CHALMERS
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Enablers and barriers to adoption of residential solar PV

A case study on Swedish households

Master's thesis in Management and Economics of Innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
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Acknowledgments, dedications, and similar personal statements reflect the author's own opinions.

The cover is an AI-generated illustration by OpenAI’s ChatGPT 4o of a residential solar PV system

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ABSTRACT

Climate change threatens society and crucial ecosystems, with urgent reductions of greenhouse gas emissions , with renewable energy sources like residential solar photovoltaic (PV) systems offering a viable solution. This master's thesis explores the evolving enablers and barriers to the adoption of residential solar PV systems in Swedish households since 2018. Utilizing a qualitative research design, the study gathers data through semi-structured interviews with recent adopters and triangulates these findings with secondary data from a quantitative survey. The empirical findings are then compared to findings from previous case studies on enablers and barriers to adoption of residential solar PV in Sweden.

The study utilizes several theoretical frameworks to analyze adoption factors, including Rogers' Diffusion of Innovation Theory, Pereira's Sensemaking Model, and Venkatesh et al.'s Unified Theory of Acceptance and Use of Technology. Identified enablers include financial benefits from reduced electricity costs and the potential to sell excess electricity, environmental concern, social influence, technology interest, and the desire for energy independence. Additionally, a significant new enabler is the synergy between residential solar PV systems and electric vehicles, enhancing both financial and environmental benefits.

Persistent barriers to adoption include high initial costs, administrative hurdles, lack of clear information from suppliers, and property-specific issues such as roof orientation and condition. Although financial barriers have weakened due to decreased installation costs and improved subsidies, administrative and informational challenges continue to impede adoption.

The findings underscore the importance of performance expectancy, effort expectancy, and social influence and interaction in driving adoption. The study suggests that enhancing institutional support and simplifying regulatory processes could further accelerate the adoption of residential solar PV systems in Sweden. The evolving landscape of enablers and barriers highlights the dynamic nature of technology adoption and the need for continuous adaptation of policies and support mechanisms.

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Keywords: residential solar PV, residential solar photovoltaics, solar energy, renewable energy technology, innovation adoption, technology acceptance.

Acknowledgements

This master's thesis was conducted as part of the master's program Management and Economics of Innovation at the Department of Technology Management and Economics, Chalmers University of Technology. Firstly, I would like to thank all of the respondents to my interviews for devoting their time to answer my questions. I also want to thank my examiner, Ksenia Onufrey. Your feedback has been immensely important for my work. Finally, I want to express the greatest of gratitude to my supervisor Lisa Bastås. You have consistently pushed me to dive deeper and produce better material. This thesis would, without question, not have been possible without your guidance and support.

Erik Juliusson, Gothenburg, June 2024

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1. Introduction

In this chapter the background, purpose, and research questions are presented with the purpose of giving insight as to why the study is relevant to research and how the problem is approached.

1.1. Background

Climate change is a known threat to society and to avoid not only destroying crucial ecosystems, but also to save human lives, scientist stress the urgency of reducing greenhouse gas emissions to dampen the effects by using renewable and non-fossil sources, such as solar photovoltaic (hereafter referred to as PV) systems, for energy production (United Nations, n.d.). Solar PV has great potential to reduce emissions of greenhouse gases, and residential solar PV systems can effectively be installed on roofs for decentralized energy production (International Energy Agency, n.d.). Simultaneously, households have been seen to account for a quarter of the total energy use in Europe (Raven et al., 2021) and are becoming increasingly relevant in supporting renewable energy transitions (Karjalainen & Ahvenniemi, 2019).

However, adoption of new technologies is not automatic and is dependent on several factors related to individual benefit, social factors, and technological factors (Abbas et al., 2022; Briscoe et al., 2011). The adopter's needs must be satisfied by the technology, and in the case of residential solar PV it requires high-involvement behavior from the adopter as the potential adopter needs to extensively weigh the pros and cons (Jager, 2006). Barriers such as high cost and inadequate policy support can hinder these needs from being fulfilled and stunt the adoption process (Karjalainen & Ahvenniemi, 2019). Existing theoretical models provide insights into why, how, and at what rate individuals decide to adopt a technology by emphasizing different aspects of adoption.

The time at which individuals adopt an innovation depends partly on the characteristics of the potential adopters and divides them into different categories based on their *innovativeness*. As different adopter categories value innovations differently, later adopter categories adopting solar PV means new aspects of the technology can become enablers or barriers to its adoption (Rogers, 1983). When individuals of the different adopter categories start to learn about an innovation, they go through stages of adoption. The stages are knowledge, persuasion, decision, implementation, and confirmation (Rogers, 1983). This linear model can be compared to the sensemaking model where individuals use previous actions to learn and guide their future decisions in a cyclical process (Pereira, 2002). It is therefore more focused on how individuals understand technologies based on their previous experience. A theory which combines elements of several different theories is the Unified Theory of Acceptance and Use of Technology (UTAUT), which emphasizes four determinants to adoption: performance expectancy, effort expectancy, social influence, and facilitating conditions (Venkatesh et al., 2003).

Despite the large amount of research conducted on innovation adoption and the benefits of renewable energy and residential solar PV, the adoption of renewable energy technologies (hereafter referred to as RETs) has been slow (Mignon & Bergek, 2016; Negro et al., 2012). Meanwhile, the potential for increasing the number solar energy installations in Sweden is high (Andersson et al., 2021) and more installations are needed to meet the future energy demand (Statens energimyndighet, 2023), which is increasing rapidly (Holmberg & Tangerås, 2022).

To better understand why adoption has occurred and why it has not occurred at a faster rate, previous studies have investigated and analyzed residential adoption of solar PV in Sweden (Bergek & Mignon, 2017; J. Palm, 2018; J. Palm & Tengvard, 2011). These studies have identified both enablers and barriers to adoption of residential solar PV. In terms of enablers, they have found environmental concern to be one of the primary enablers for adoption, with technology interest and a desire to be energy independent enabling adoption of residential solar PV further (Bergek & Mignon, 2017). The financial aspect of investing in solar PV has moved from being a barrier (J. Palm & Tengvard, 2011) towards, in some cases, being an enabler for adoption as the general cost for solar PV has decreased, subsidies have stimulated adoption, and it is possible to generate revenue by selling excess electricity to the grid (J. Palm, 2018). Regarding the barriers to adoption, despite the mentioned cost decreases, the cost of solar PV installation has still been identified as a barrier to adoption of residential solar PV (Bergek & Mignon, 2017; Palm, 2018). Another barrier is the lack of clear information regarding the installation and benefits of solar PV (Mignon & Bergek, 2016; J. Palm, 2018). Lastly, administrative hurdles have created a barrier to adoption due to the numerous application processes needed for the use of residential solar PV (J. Palm & Tengvard, 2011).

In recent years, several events and changes have affected society and therefore potentially also influenced the enablers and barriers to adoption of residential solar PV. For instance, climate related issues have increased the urgency of transitioning to renewable energy sources (World Meteorological Organization, 2021), COVID 19 has negatively impacted communication efforts regarding new energy projects (Busch & Hansen, 2021), Russia’s invasion of Ukraine has affected Europe’s energy supply (European Council, 2024), the cost of electricity in Sweden has increased (Konsumenternas energimarknadsbyrå, n.d.), and increased adoption of electric vehicles (hereafter referred to as EVs) in Sweden (Trafikanalys, 2024) has led to increased electricity demand (Statens energimyndighet, 2023). While adoption of residential solar PV has still continued (EurObserv’ER, 2023), the enablers and barriers to adoption can potentially be different than during previous studies. This study aims to address the knowledge gap in research by increasing the understanding of the current enablers and barriers to adoption of residential solar PV in Swedish households, and how they have developed from previous enablers and barriers.

1.2. Purpose

The purpose of the study is to understand how the enablers and barriers to adoption of residential solar PV systems for Swedish households have changed since 2018 and what has led to the changes.

With this purpose, the following research questions have been formed:

1. How have the enablers to adoption of residential solar PV in Sweden evolved since 2018?

2. How have the barriers to adoption of residential solar PV in Sweden evolved since 2018?

3. What can explain the differences between the current and previous enablers and barriers to adoption of residential solar PV in Sweden?

1.3. Outline of the thesis

Chapter 2 of the thesis provides a theoretical background for the reader to get a deeper understanding of the existing innovation adoption theory and case studies on residential solar PV in Swedish households. Chapter 3 presents the methodology of the study, followed by chapter 4 and the empirical findings. In Chapter 5 the findings are analyzed and connected to the theoretical background. Chapter 6 discusses the implications of the study and future considerations. Lastly, chapter 7 presents the conclusion.

2. Theoretical background

The theoretical background consists of literature on adoption theory as well as empirical findings on enablers and barriers to adoptions of residential solar PV in Sweden. By combining the theoretical models and connecting them to the identified enablers and barriers to adoption of residential solar PV a broader understanding of the adoption process can be achieved.

2.1. Innovation adoption theory

Adoption has been described differently by researchers. Some scholars refer to adoption as the decision to implement solution or practice (Hollweck, 2015). In contrast, others refer to adoption as the process of researching, implementing, and utilizing an innovation, instead of focusing only on the decision itself (Hall et al., 1975). Although these different views on adoption exist, innovation adoption generally refers to how innovations are introduced to individuals or organizations, how the adoption decision is reached, and how the rate of the process is affected by different circumstances or factors (Davis, 1989; Rogers, 1983; Venkatesh et al., 2003). For adoption to occur, various needs of the potential adopters need to be satisfied by the innovation (Jager, 2006). These can for example be a need for social belonging (Briscoe et al., 2011) or cost reductions (Qureshi et al., 2017). s

To model the rate at which different individuals adopt an innovation, individuals are grouped into the following categories: innovators, early adopters, early majority, late majority, and laggards. The basis for the categorization is the degree of innovativeness each individual has. High income, high education, living in urban areas, high interest in technology, and an aptitude for risk are some of the characteristics indicating high innovativeness and therefore earlier adoption (Rogers, 1983). Rogers' model has, however, been subjected to critique and opposition (Lyytinen & Damsgaard, 2001; Ruokamo et al., 2023; Seligman, 2006). For example, in a recent case study on residential solar PV in Finland, no statistically significant association was found between high income and early adopters (Ruokamo et al., 2023). The study by Ruokamo et al. (2023) also found that individuals living in rural areas were more likely to adopt solar PV and to be early adopters, in comparison to individuals in urban areas. While some aspects of Rogers' model are corroborated, it is clear that the model needs to be complemented with other perspectives were the individual's thought process is taken into further account (Seligman, 2006). This a major reason for why Pereira's (2002) sensemaking model, which is explained deeper in the chapter 2.1.2, is included in the study.

The major adoption theories chosen for this thesis are the diffusion of innovation by Rogers (1983), sensemaking by Pereira (2002), and the unified theory of acceptance and use of technology by Venkatesh et al. (2004). Rogers' diffusion of innovation has been applied to studies in various subjects, including solar PV (García-Avilés, 2020; A. Palm & Lantz, 2020; Ruokamo et al., 2023). Little research has, however, been conducted on solar PV using the sensemaking perspective by Pereira (2002) and the UTAUT by Venkatesh et al. (2004). However, these theories have been used to analyze the adoption of IT systems (Ayaz &

Yanartaş, 2020; Polyviou et al., 2023), and are deemed suitable for analysis of residential solar PV as well, since IT systems share some similarities with residential solar PV. Both are adopted by individuals with little to no experience of the technology (Mignon & Bergek, 2016) and, while the magnitude of the adoption decision can be different and irreversible in the case of solar PV, the process leading up to the decision is similar.

2.1.1. Diffusion of innovation

The first adoption theory to be used for the analysis is the diffusion of innovation theory (Rogers, 1983). Apart from the adopter categories already mentioned, the adoption rate of an innovation is also influenced by the innovation's attributes (Rogers, 1983). The three attributes of an innovation most relevant for this study are its relative advantage, compatibility, complexity, and observability. Relative advantage refers to what a specific innovation offers that is not offered by another innovation, and for solar energy this has been found not to be sufficient (Bandara & Amarasena, 2018). Compatibility concerns how consistent the innovation is with individual values and needs (Rogers, 1983), and high compatibility decreases the uncertainty involved with adopting an innovation (Sahin, 2006). One example of compatibility issues with residential solar PV was found in Pakistan where the environmental aspect of solar PV was not compatible with their priorities of reducing costs (Qureshi et al., 2017). The complexity is mentioned by Qureshi et al. (2017) to influence the adoption rate of residential solar PV as complicated technologies are adopted more slowly as compared to simpler innovations. Lastly, if an innovation is visible to neighbors and friends the innovation's observability can increase the adoption rate as it stimulates discussions regarding the innovation (Rogers, 1983). This is regarded as a main factor for adoption of a technology (Sahin, 2006).

Diffusion of innovation theory presents a linear model of the adoption process occurring through five stages: knowledge, persuasion, decision, implementation, and confirmation (Rogers, 1983). The knowledge stage is where the individual is first exposed to the innovation and starts to understand its functionality (Taylor et al., 2018). During the persuasion stage, the individual contextualizes the innovation and weighs its pros and cons, and targeted efforts should be made to highlight the relative advantages of the innovation. At this stage, the individual's attitude towards the innovation is shaped (Taylor et al., 2018). At the decision stage, the individual chooses to either adopt or reject the innovation (Rogers, 1983). For residential solar PV, this could include scouting for suppliers and comparing costs and benefits between solar PV and other solutions. If the individual chooses to adopt, they continue to the implementation stage where the usefulness of the innovation is determined and later evaluated in the confirmation stage where the individual can choose to reverse the adoption decision (Rogers, 1983). As residential solar PV adoption is essentially non-reversible, only the knowledge, persuasion, and decision stage are seen as relevant for the study.

2.1.2. Sensemaking model

The linear adoption process from diffusion of innovation theory can be complemented by Pereira's (2002) sensemaking model, which emphasizes how previous decisions to adopt a technology guides future decisions of adoption. This cyclical process means that as individuals reinterpret an innovation's role in their lives, their assessment of the innovation and future innovations change (Pereira, 2002).

The concept of sensemaking consists of certain properties including identity, retrospect, social contact, and ongoing events (Weick, 1995). These properties are connected to technology adoption in different ways. Adopting technologies impacts one's identity construction, for example by making the user consider themselves intelligent (Seligman, 2006). Sensemaking being retrospective means that individuals only make sense of past experiences. This affects adoption attitudes as past experience with a technology resulting in success or failure leads to a changed attitude for future technologies (Pereira, 2002). Social contact impacts adoption as an individual's mental framework is influenced by the mental framework of others in their social group. Ongoing events concern how over time systems, and environmental and contextual conditions change, leading to individuals intending to adopt a technology but not doing so as a result of different circumstances (Pereira, 2002; Seligman, 2006).

As mentioned, it has been noted that Roger's diffusion of innovation theory insufficiently takes the individual into account when comparing the sensemaking perspective to Roger's (1983) adoption process (Seligman, 2006). To combat this, each adoption stage described by Rogers can be viewed at a deeper level by focusing on the adopter and their mental frameworks, and how sensemaking occurs at each individual stage (Pereira, 2002; Seligman, 2006). The activity of sensemaking at each stage is what propels the individual onto the next stage in the process, and Pereira's sensemaking model can therefore be used to better understand the adoption process by complementing Rogers' (1983) model with a more dynamic perspective within each stage of adoption.

Figure 1 illustrates how the sensemaking model (Pereira, 2002) can be used to extend the adoption process model (Rogers, 1983). It shows how sensemaking occurs within each individual stage of adoption, but also between different adoption processes and guides future decisions.

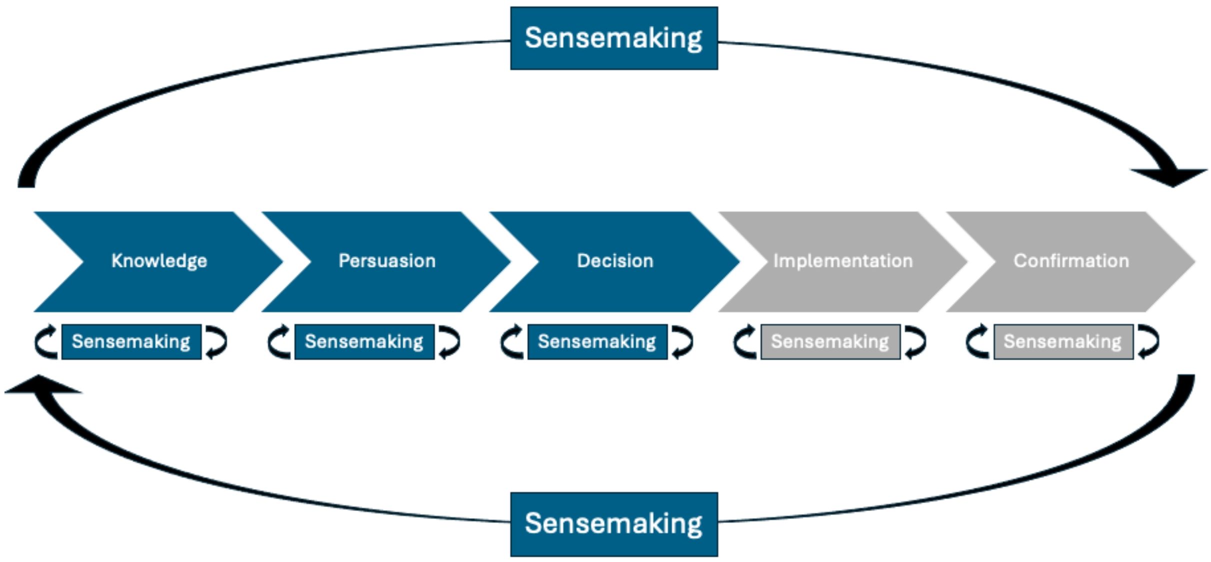

Figure 1. Rogers' (1983) adoption process extended with Pereira's (2002) sensemaking model. Implementation and confirmation stages greyed out due to not being relevant.

2.1.3. Unified Theory of Acceptance and Use of Technology

A third and final model is the Unified Theory of Acceptance and Use of Technology (UTAUT) model by Venkatesh et al. (2003). The UTAUT model builds upon several previous models from different theoretical areas. One of the models incorporated into the UTAUT is the technology acceptance model (TAM) by Davis (1989). TAM states that the critical factors in the decision for an individual to adopt and use a technology is its perceived usefulness and its perceived ease of use (Davis, 1989). The perceived usefulness is related to what degree an individual believes the technology would enhance their performance, and the perceived ease of use is the degree to which an individual thinks using a new technology will be effortless. These two key constructs in TAM by Davis can be directly connected to the first two determinants for technology acceptance in the UTAUT model: *performance expectancy* and *effort expectancy* (Venkatesh et al., 2003). These two determinants also encapsulate the attributes relative advantage (performance expectancy) and complexity (effort expectancy) mentioned by Rogers (1983).

The UTAUT also incorporates the theory of planned behavior (TPB) by Aizen (1991). TPB features constructs such as subjective norms and attitude, which have been condensed into the third determinant of technology acceptance in the UTAUT: *social influence*. This determinant emphasizes the role of social norms and social pressure in adoption (Venkatesh et al., 2003). The UTAUT's social influence can therefore be connected to both the socioeconomic factors mentioned by Rogers (1983) in his diffusion of innovation theory and the dynamic social context by Pereira (2002) in his sensemaking model.

TPB is also integrated into the fourth and final determinant in the UTAUT model. In TPB, the concept of control beliefs concerns if an individual believes there are factors that facilitate or hinder a behavior (Aizen, 1991). In the UTAUT, this concept can be found in the *facilitating conditions* determinant, where facilitating conditions is the degree to which an individual believes a technological system has infrastructural support (Venkatesh et al., 2003).

In sum, the four determinants for technology acceptance or adoption according to the UTAUT are performance expectancy, effort expectancy, social influence, and facilitating conditions.

2.2. Adoption of residential solar PV

The adoption of RETs has been shown to progress slowly, and part of the reason for the slow progress can be attributed to "hard" institutions, such as regulations and policies, and "soft" institutions, such as social norms and behaviors (Negro et al., 2012). Various studies have highlighted similar or different factors influencing, either positively as enablers or negatively as barriers, the adoption rate of residential solar PV and other RETs in different countries and regions (Abbas et al., 2022; Bandara & Amarasena, 2018; Bao et al., 2020; Qureshi et al., 2017; Ruokamo et al., 2023). In Pakistan, it was found that the most significant enabler to adoption of solar PV was the environmental benefits it brings. Other enablers include solar PV providing a consistent energy supply and social acceptability (Qureshi et al., 2017). The same study identified that the most significant barrier was the high cost for solar PV systems, followed by insufficient governmental support. In California and Massachusetts, cost saving was instead found as one of the most important enablers to adoption (Bao et al., 2020).

As the enablers and barriers to adoption of residential solar PV can differ between countries, this study's empirical findings are compared to the previous enablers and barriers to adoption of residential solar PV in Swedish households. These were mainly found in case studies by Palm & Tengvard (2011), Bergek & Mignon (2017), and Palm (2018).

2.2.1. Previous enablers to adoption of residential solar PV

The enablers identified in the above-mentioned studies have been divided into five themes: environmental, social, financial, technology interest, and energy independence.

Financial
Financial enablers vary in shape but in general they concern how having a solar PV system can reduce electricity costs or generate revenue by selling electricity to the power grid. This has been highlighted as an enabler to adoption by several studies (Bergek & Mignon, 2017; J. Palm, 2018; J. Palm & Tengvard, 2011). However, it has also been a barrier (J. Palm, 2018; J. Palm & Tengvard, 2011). The potential financial long-term savings was initially a relatively weak enabler but existed due to an anticipation of future benefits (J. Palm & Tengvard, 2011). By 2014-2016 it had, however, become a significant enabler to the adoption of solar PV as result

of decreased installation costs, subsidies, and the ability to sell excess capacity to the power grid (J. Palm, 2018), as well as the reduced energy costs solar PV systems provide.

Financial aspects being enablers of solar PV adoption can be related to several elements of the different adoption models. The anticipated benefits of the installation can be connected to the performance expectancy in the UTAUT model (Venkatesh et al., 2003). Furthermore, the ability to sell excess capacity to the power grid and the governmental subsidies indicate infrastructural support for the technology (J. Palm, 2018), showing the existence of facilitating conditions from the UTAUT model. It can also be seen as to have increased the anticipated long-term benefits and by extension the perceived usefulness and performance expectancy.

Decreased installation costs, subsidies, the ability to sell excess capacity (J. Palm, 2018), and reduced energy costs (Bergek & Mignon, 2017) also lead to decreased financial risk. Rogers (1983) identifies risk aversion as a key characteristic for categorizing adopters, with less risk-averse individuals often exhibiting higher levels of innovativeness. Consequently, reducing financial risk could encourage less innovative groups to consider investing in solar PV.

Environmental

Environmental enablers are the aspects of solar PV related to environmental concern and a desire to be more environmentally friendly. J. Palm & Tengvard (2011) found that this was main enabler for installation of solar PV in private households. The authors showed that this enabler came from a general desire to be sustainable and to a decrease in one's ecological footprint. Environmental concern being the primary enabler for adoption of solar PV is further supported by later case studies. In their study of motives to adopt RETs, Bergek & Mignon (2017) identified different groups of adopters and their motives, and the group consisting of individuals was seen to primarily be motivated by environmental concern. While these two case studies are six years apart, environmental concern has persisted as a main enabler (Bergek & Mignon, 2017; J. Palm & Tengvard, 2011). J. Palm (2018) further confirms this in a study comparing the enablers between 2008-2009 and 2014-2016, stating that environmental concern as an enabler has remained consistent.

Environmental concern being the primary enabler for adoption of solar PV among Swedish households is in line with findings from studies on other countries and regions (Karjalainen & Ahvenniemi, 2019; Qureshi et al., 2017) and reflects the emphasis on social norms and pressure as a determinant for adoption. Climate change awareness in Sweden is high and, in a survey, when asked if one thinks climate change will affect Swedish citizens 90% answered yes in 2015, which increased to 95% in 2018 (PFM Research, 2018). As more individuals become aware of how society will be affected by climate change, it can be expected that the social pressure to be more environmentally friendly increases, in line with the social influence determinant (Venkatesh et al., 2003) and the sensemaking model (Pereira, 2002).

Social

In residential solar PV adoption, social factors concern how having a solar PV system can influence others, increase one's social status in the community, or protest against the incumbent actors. The investment in solar PV could be seen as a symbolic investment to show environmental consciousness and inspire others to adopt (J. Palm & Tengvard, 2011). According to the same study, it was also a means of protest against the large incumbent energy actors and oppose the use of non-renewable energy. The act of influencing others to adopt an innovation is mentioned by Rogers (1983) as a characteristic for primarily the early adopters, where the early adopters provide credibility to the innovation. Innovators are also influential, but less so due to their smaller population and their high-risk tolerance.

Technology interest

Technology interest as an enabler to adoption is related to how an interest in new technologies can incentivize adoption of them. Similarly to Finland (Ruokamo et al., 2023), interest in the technology of solar PV has been considered an enabler to the adoption, although mostly during the period 2008 until 2010 (J. Palm, 2018). While still prevalent in the latter period between 2014 and 2016, this aspect was not as significant as before, according to J. Palm (2018). Bergek & Mignon (2017) also found that technology interest was one of the enablers to adoption in their study, supporting the findings of both J. Palm & Tengvard (2011) and J. Palm (2018).

Interest in new ideas and technologies is a characteristic mentioned by Rogers (1983) as one of the most prominent among innovators, the first of Rogers' (1983) adopter categories. The decreasing significance of technology interest as an enabler could therefore be an indicator that adopter groups with less innovativeness have started to adopt solar PV.

Energy independence

Enablers related to energy independence is connected to how households want to be self-sufficient and able to generate power off-grid, or for example be able charge their EVs with own-produced electricity. With the increased availability of EVs, more households wanted to invest in solar PV to be able to charge their car and become independent of energy companies (J. Palm, 2018). The desire to be self-sufficient and independent of energy companies is also mentioned as an enabler by Bergek & Mignon (2017) and J. Palm & Tengvard (2011).

Similarly to the financial enabler, the anticipated benefit of energy independence can be related to the performance expectancy determinant (Venkatesh et al., 2003) and the relative advantage attribute (Rogers, 1983).

Summary of enablers

The previous enablers to adoption of residential solar PV are summarized in table 1 below and together with how they were identified and from what reference.

Type	Reason	Reference
Financial	Decreased costs, subsidies, selling to grid	J. Palm & Tengvard (2011), Bergek & Mignon (2017), J. Palm (2018)
Environmental	Environmental concern	J. Palm & Tengvard (2011), Bergek & Mignon (2017), J. Palm (2018), Mundaca & Samahita (2020)
Social	Social status and influence	J. Palm (2018)
Technology interest	Interest in solar cell technology	J. Palm & Tengvard (2011), Bergek & Mignon (2017), J. Palm (2018)
Energy independence	Charge EV, be independent of energy companies	J. Palm & Tengvard (2011), Bergek & Mignon (2017), J. Palm (2018)

Table 1. Enablers to adoption of residential solar PV.

2.2.2. Previous barriers to adoption of residential solar PV

The barriers mainly identified in the case studies by Bergek & Mignon (2017), J. Palm & Tengvard (2011), and J. Palm (2018) have been divided into three themes: financial, administrative, and lack of information.

Financial

As mentioned in the chapter 2.2.1, financial aspects of residential solar PV have not only been an enabler to adoption. The cost for installing solar PV has still been substantial, making households contemplate the decision longer (J. Palm, 2018; J. Palm & Tengvard, 2011), and can be expected to have hindered some from adopting entirely. However, the barrier weakened between 2008-2009 and 2014-2016 due to the decreased cost and policy interventions previously mentioned (J. Palm & Tengvard, 2011).

From 2015 to 2020, the cost for solar cells decreased by 74% (Internation Energy Agency, 2022). This could lead to the barrier of investment cost having weakened even more, as a large part of this 74% decrease occurred after J. Palm's (2018) study. Furthermore, the policies aiming to increase adoption by subsidizing the installation cost have been subjected to several changes (Mundaca & Samahita, 2020). Between 2009 and 2017, the subsidy amount was gradually lowered from 60% of the installation cost to 30% of the installation cost (Mundaca

& Samahita, 2020), before finally being replaced by a tax relief for green investments in 2021 (Skatteverket, 2024). The lowered subsidy amount and eventual change to a tax relief can be thought to have impacted the financial barrier as well.

Administrative

The administrative barriers concern processes and regulations that delay the installation and use of the complete system. While unclear regulations and administrative hurdles were identified as significant barriers to adoption during the period between 2008 and 2009 (J. Palm & Tengvard, 2011; J. Palm, 2018), it had surpassed installation cost regarding its significance as a barrier by 2014, due to the increased number of administrative tasks related to subsidy application, grid connection, and selling electricity to the grid (J. Palm, 2018). This is supported by Mundaca & Samahita (2020) stating how the changes made to the subsidy program made it unclear how much the system would be subsidized when the subsidy application was filed.

Despite subsidies and selling electricity to the grid being enablers to adoption from a financial perspective, these same factors increased the administrative barriers as the installation process became more complex (J. Palm, 2018). As mentioned, these factors showed the existence of infrastructural support and facilitating conditions in the UTAUT model, but because of the increased difficulty of navigating through the process these facilitating conditions were weakened.

Lack of information

A final barrier to the adoption of residential solar PV is the lack of information regarding suppliers and installation companies, different PV panels, as well as how to sell electricity to the grid (J. Palm, 2018). J. Palm (2018) states how with the expansion of the market numerous installation companies could be chosen, some of which did not deliver on time nor meet all regulations.

How a lack of information has formed a barrier and slowed down the adoption could be related to the initial steps of Rogers' (1983) model: knowledge and persuasion. Because of the unclear information from installation companies, the time it took for households to be persuaded to install solar panels increased.

Summary of barriers

The previous barriers to adoption of residential solar PV are summarized in table 2 below and together with how they were identified and from what reference.

Type	Reason	Reference
Financial	High installation cost	J. Palm & Tengvard (2011), J. Palm (2018), Mundaca & Samahita (2020)
Administrative	Increased number of administrative tasks. Subsidy application, grid connection, selling electricity	J. Palm & Tengvard (2011), J. Palm (2018), Mundaca & Samahita (2020)
Lack of information	Lack of information regarding suppliers and technical proposals	J. Palm (2018)

Table 2. Barriers to adoption of residential solar PV.

2.3. Combined framework for analysis of empirical findings

The theories and models presented in chapter 2.1 have been combined into a comprehensive framework for analyzing the current enablers to adoption of residential solar PV in Sweden. It mainly draws inspiration from the UTAUT model but is further enhanced by insights from Rogers' diffusion of innovation and Pereira's sensemaking model.

Mainly revolving around the UTAUT model by Venkatesh et al. (2003), the aspects of enablers and barriers to residential solar PV related to its electricity production and consequences thereof can be analyzed using the performance expectancy determinant, and therefore also the relative advantage mentioned by Rogers (1983).

To analyze how the complexity of solar PV technology impacts the enablers and barriers to adoption, both regarding usage and installation, the effort expectancy from the UTAUT model can be applied. The effort expectancy and the performance expectancy can then be looked at from a higher perspective using Rogers' (1983) process stages as the knowledge and persuasion stage is where the individual learns about the innovation and weighs the pros and cons.

Aspects of enablers and barriers to residential solar PV related to social norms, social pressure, socioeconomic status, and other social factors are analyzed using the social influence determinant by Venkatesh et al. (2003), and the adopter categorization and observability attribute by Rogers (1983). As these factors all impact the individuals on a personal level, Pereira's (2002) sensemaking model is also applicable for the analysis of these aspects.

Institutional and infrastructural support or opposition to the adoption of residential solar PV, as well as support or opposition stemming from external factors can be analyzed using the facilitating conditions by Venkatesh et al. (2003). These aspects are, however, also analyzed using other elements of the framework as they can be expected to impact the enablers and barriers to adoption from several angles. Similarly, facilitating conditions can in turn affect the system's performance and therefore also be applied to different aspects of the enablers and barriers to adoption. The facilitating conditions and Rogers' (1983) compatibility attribute can be utilized together to analyze whether synergies and compatibilities can enable or hinder the adoption.

Since sensemaking occurs within every adoption stage (Seligman, 2006), the sensemaking model by Pereira (2002) is applicable to all of the mentioned aspects of solar PV, although most notably the social ones as they are connected to how the individual adopter contextualizes and makes sense of them. Sensemaking is thus not as specific in its application to the study, but more so a concept to understand each enabler and barrier on a deeper and more personal level in general.

The framework is summarized in the following table:

Aspects	Theories/models applied	Explanation
Electricity production and consequences	UTAUT model (performance expectancy), Diffusion of innovation (relative advantage)	Analyzes how electricity production and its outcomes impact adoption, focusing on performance expectancy and relative advantage. Connects to enablers dependent on how much electricity is produced, e.g. financial and environmental.
Installation and usage	UTAUT model (effort expectancy), Diffusion of innovation (process stages: knowledge and persuasion)	Examines the impact of complexity on adoption using effort expectancy and considers the knowledge and persuasion stages where individuals learn about and evaluate the innovation. Connects to administrative barriers and a lack of information.
Social	UTAUT model (social influence), Diffusion of innovation (observability)	Analyzes social aspects influencing adoption through social influence and observability. Can be connected to several enablers and social interactions.
Institutional and infrastructural support	UTAUT model (facilitating conditions), Diffusion of innovation (compatibility)	Evaluates how external support or opposition impacts adoption, using facilitating conditions and compatibility to understand synergies and barriers. Relevant for analyzing administrative barriers and enabling synergies with EVs.

General sensemaking across all aspects	Sensemaking model	Applies sensemaking to all stages of adoption to provide a deeper, personal understanding of enablers and barriers.

Table 3. Combined framework for analysis of empirical findings

3. Method

The thesis is a qualitative case study on adopters of residential solar PV in Sweden to understand how the enablers and barriers to adoption have evolved during the past few years.

3.1. Research design

The study has used a qualitative research strategy to analyze the relationship between theory and research and has therefore been based on data comprised of words and phrases rather than numbers (Bell et al., 2019). A qualitative study is appropriate as the case study has aimed to understand the diffusion of a technology involving several factors in a broad context (Denscombe, 2017), and furthermore a qualitative research strategy is regarded as appropriate for the investigation of individuals' behavior (Bell et al., 2019).

The study uses an abductive approach as the data collection and interpretation, and the theoretical work has been an iterative process where the research questions have been reformulated and more specified as the study has proceeded (Bell et al., 2019). Abductive reasoning is closely connected to inductive reasoning, with a difference being that inductive reasoning means the theory is the result of the research (Bell et al., 2019). This study has instead attempted to use theoretical frameworks to analyze the empirical findings and refine the theory instead of generating new theories, which is a key purpose of abductive reasoning (Dubois & Gadde, 2002).

3.2. Study context

The context of the study is solar PV adoption by Swedish households. There are two reasons for the Swedish context being chosen. Firstly, the potential for solar PV in Sweden is estimated to be 40 TWH/year (Andersson et al., 2021), while currently only 1.963 TWh/year is being produced (EurObserv'ER, 2023). Regarding RETs in general, Sweden is one of the frontrunners in Europe mainly due to large-scale hydro power, wind power, and biomass (Bergek & Mignon, 2017). Renewable energy accounted for 67% of the energy production in 2022 and 58% of the energy consumption in 2020 (International Energy Agency, 2022)

Another reason why Sweden and residential solar PV is particularly interesting is the changes to governmental support for the adoption of solar PV. Before 2021, a subsidy was given for the installation of residential solar PV (Mundaca & Samahita, 2020), which has since been replaced by a tax relief for green investments (Skatteverket, 2024).

3.3. Data collection

Data collection has been conducted in two ways. The primary data collection was done through qualitative and semi-structured interviews. This allows for the interviews to be flexible and the respondents to provide insights they themselves found relevant (Bell et al., 2019). The interviews roughly followed an interview guide, found in appendix A, to ensure the most important information was collected, while remaining flexible to allow follow-up questions. The interview guide was generally based on previous case studies by Bergek & Mignon (2017), J. Palm & Tengvard (2011), and J. Palm (2018) to allow for direct comparisons between the empirical findings and previous findings. To explore paths that had been identified during previous interviews, the interview guide was changed as the primary data collection progressed (Bell et al., 2019). The answers to interview questions were often ambiguous and could not be quantified, which legitimized the choice of a qualitative study (Franzosi, 1997). Recording of the interviews was done in all interviews as the respondents consented to being recorded. This was valuable as not only the response itself was of interest, but also how the response was given (Bell et al., 2019).

The respondents were identified and included in the study through a generic purposive sampling process, as generic purposive sampling is relatively open-ended and suitable for the generation of concepts and theory (Bell et al., 2019). The criteria that qualified an individual to be interviewed was that the respondents must have adopted residential solar PV during 2020 or after. The respondents were found and approached for an interview through various channels. Some of the respondents were recommended by peers, some through social media, and some from a previous research project which is further elaborated on in the following paragraph. In total, eight interviews were conducted between March and May of 2024, all of them using Microsoft Teams and lasting between 35 and 50 minutes. Out of the eight respondents, seven were male and one was female, everyone between the ages 45 to 70.

The findings from the qualitative interviews were triangulated, meaning cross-checked with data from another study (Bell et al., 2019), using secondary data from a previous study as part of a research project at Chalmers University of Technology called "Public energy advising as a policy instrument for a large-scale diffusion of solar photovoltaics – a study of the Swedish municipal energy and climate advising", which was financed by the Swedish Energy Agency.[1] The study used a quantitative survey to collect data, and its purpose was to understand aspects affecting the decision to adopt solar PV. The sample included households which had adopted solar PV between 2009 and 2021 and with a response rate of 36%, 16 888 responded to the survey. The secondary data used to triangulate empirical findings came from an analysis of 16 free-text answers where respondents to the survey could elaborate on their answers, as these answers confirmed or contrasted some of the findings made in the primary data collection. An example of secondary data included in the study is answers mentioning how difficult it was to find serious suppliers. To stay within the scope of the study, only answers where it is stated that adoption occurred in 2020 or after were included. Some of the answers fitting the criteria were not included as those respondents were instead approached for an interview, as they had stated they were open for follow-up discussions and submitted their contact information.

[1] Link to the project page: Public energy advising as a policy instrument for large-scale diffusion of solar photovoltaics – a study of the Swedish municipal energy and climate advising (chalmers.se)

To separate respondents from the primary data collection and the secondary data collection, the respondents to the qualitative interviews are referred to as A, B, C, …, while respondents to the survey are referred to as a pure number, e.g. 133.

3.4. Data analysis

To analyze the data, a thematic analysis was conducted, where the themes or categories were identified through analysis of data and from previous case studies on residential solar PV in Sweden, while having a relation to the research questions (Bell et al., 2019). It is a flexible strategy that is useful for many types of data. In the case of the study, the transcribed interviews were coded and labeled to identify reoccurring topics and match the topics to the identified themes. This approach was suitable as the study aimed to identify different enablers and barriers to the adoption of residential solar PV, and by identifying reoccurring topics these factors could be pinpointed and analyzed using the framework presented in chapter 2.3.

As mentioned, the themes were in most cases also found in the previous case studies (Bergek & Mignon, 2017; J. Palm, 2018; J. Palm & Tengvard, 2011), but two were found during the interviews. The themes were separated into enablers and barriers to adoption of residential solar PV and the following themes were identified:

Enablers	**Barriers**
Financial	Financial
Environmental	Administrative
Social	Lack of information
Technology interest	Property characteristics
Energy independence	
Household synergies	

Table 4. Identified themes for enablers and barriers to adoption of residential solar PV

Among the enablers, the financial theme concerned topics related to financial gain, such as reduced electricity costs, selling excess electricity to the grid, and investing in the property. The topics within the environmental theme were mostly related to a general concern for the environment. Social topics concern how friends and family were influenced by adopters to follow suit and if increasing one's social status was a reason for installing solar PV. The theme technology interest is rather self-explanatory as respondents with interest in RETs were inclined to install solar PV. Energy independence relates to how households wanted to be more self-sufficient and produce their own electricity, decreasing their dependence on energy actors. Lastly, the theme household synergies was constructed for this study to better encompass enablers related to EVs or property characteristics and analyze them separately from the other themes.

In terms of barriers, the financial theme included topics of installation and maintenance costs. The administrative theme included topics regarding application processes and regulative hurdles. On the theme of a lack of information, topics that were brought up concerned both a lack of information regarding suppliers and a lack of information regarding the technical proposals provided by suppliers. Lastly, the theme property characteristics was constructed for this study as it was identified that the roof where the solar PV system is intended to be installed has to, for example, not be too old or due a renovation.

As mentioned, the themes and topics were analyzed using the combined framework from chapter 2.3. By separating residential solar PV into different aspects, for example electricity production, the enablers and barriers are analyzed regarding how they affect each of these aspects. They are then connected to the different elements of the theoretical models, such as Venkatesh et al.'s (2003) performance expectancy. The aspects used for analysis were determined based on how the determinants to adoption according to the theoretical models influence different parts of residential solar PV. By analyzing the enablers and barriers to adoption of residential solar PV this way, not only are the enablers and barriers understood separately, but also how they influence each other. This provided a better understanding of the evolution of the enablers and barriers to adoption of residential solar PV as societal changes or external events can be connected to determinants affecting different aspects. Therefore, why the evolution or change has occurred can be better explained.

3.5. Method discussion

During the course of the study, there were mainly two challenges needed to be handled. Initially, the study sought to also include non-adopters as these were thought to provide more insights into the barriers to adoption of residential solar PV. However, including non-adopters is not unproblematic. It would require more interviews to be conducted in order for conclusions to be drawn, which due to the time constraint was problematic. Furthermore, the previous case studies used to identify previous enablers and barriers to adoption did not look at non-adopters, making the comparison more difficult. Lastly, it creates the issue of what non-adopters to include and what criteria to use for sampling. Reasonably, the criteria for interview would involve the non-adopters to have progressed to a certain stage in the adoption process. The most intuitive criteria would then be for the non-adopter to have received an offer from a supplier and rejected. However, if the goal with including non-adopters is to better understand the barriers to adoption, for example the financial barrier, it can be expected that for the non-adopters who progressed to the decision stage the financial barrier was already to a large extent overcome. Using this criterion would then mean that the financial barrier was not fully encompassed either way. These several issues with including non-adopters in the study has therefore resulted in a limited scope where barriers are seen as factors delaying or prolonging the adoption process, not as factors completely inhibiting adoption from occurring. An implication of this limitation is that some barriers that fully inhibits adoption of residential solar

PV are not identified in the study. Furthermore, the financial barriers is not fully understood as households that did not overcome the financial barrier have not been interviewed.

Another challenge was how to combine the primary and secondary data collections. As the final number of interviews was rather low due to cancellations and time constraints, the primary data needed to be triangulated using secondary data. While the free-text answers to the survey used for the secondary data collection were useful, most of them were from individuals having adopted residential solar PV pre-2020. Therefore, there was a need to filter the answers to only include the relevant answers from adopters post-2019. This narrowed down the available secondary data, making it quite a lot thinner. However, the secondary data left after filtering was still highly useful and both confirmed and contrasted some of the findings from the primary data collection. They could therefore be combined rather effortlessly.

When evaluating and establishing the quality of a qualitative study, the key criteria are credibility, transferability, dependability, and confirmability. Credibility concerns how trustworthy and believable the findings of the study are (Bell et al., 2019). Several measures were taken to ensure credibility of the study. Firstly, the researcher received confirmation of having understood the answers correctly by summarizing the answers and asking if there were any misunderstandings. The researcher also recorded the interview to be able to hear the answers again, while simultaneously reading the interview transcript. Lastly, the findings from the eight interviews were given more credibility as they were triangulated by secondary data from a quantitative survey (Bell et al., 2019).

Transferability refers how applicable the findings are to other contexts (Bell et al., 2019) and was addressed by providing a description of the selected methodology, including the interview guide in appendix A, the theoretical framework, and empirical findings. This enhances the study’s transferability, as similar structures can be applied in other studies, which is crucial given the unique context often present in qualitative research. However, a disadvantage of the qualitative research design is the generalizability (Bell et al., 2019), although case studies have proven a degree of analytical generalizability (Yin, 2003).

Dependability refers to the stability and consistency of the research process (Bell et al., 2019). For dependability, the primary data collection was documented in transcriptions, leaving an audit trail that if requested can be reviewed to understand how the conclusions were drawn. Similarly, the data from the secondary data collection can be retrieved through the provided project link on page 16. Furthermore, study was regularly reviewed by a supervisor, who provided feedback and guidance to ensure the research stayed on track.

Finally, confirmability concerns how the researcher’s biases and motivations shape the study (Bell et al., 2019). While complete objectivity is impossible, the researcher has made efforts to act in good faith and prevent personal values from influencing the participants, in order to ensure confirmability of the study.

4. Empirical findings

The qualitative interviews and survey responses led to several insights concerning the current enablers and barriers to adoption of residential solar PV. As the study has used thematic analysis to analyze the data, the data was separated into enablers and barriers as themes. Within the themes, the different reoccurring topics closely resembled the enablers and barriers found in the theoretical background. For the enablers to adoption, the topics were financial, environmental, social, technology interest, energy independence, and household synergies. As for the barriers to adoption, the topics were financial, administrative, lack of information, and property characteristics.

4.1. Current enablers to adoption of residential solar PV

The enablers to adoption identified in the qualitative interviews are summarized in the following table and presented separately in their respective sections.

Enabler	**Reason**
Financial	Reduced electricity cost, sell excess electricity, invest in property
Environmental	Desire to reduce carbon footprint, general environmental concern
Social	Influenced by and having influenced others to adopt
Technology interest	Interest in RETs, previous use of solar energy for heating water
Energy independence	Generate own power, not be greatly affected by external events
Household synergies	Driving EV, southern facing roof, newly renovated roof

Table 5. Summary of enablers to adoption of residential solar PV

Financial

The empirical findings indicate that one of the main enablers for adopting solar PV technology is the financial benefit, as several respondents highlighted a desire for reduced energy costs and potential revenue from selling excess electricity. For example, Respondent A installed their solar panels in 2020 due to the shutdown of nuclear plants and an expectation on rising cost for electricity. Following the increased cost of electricity A predicted, respondent E also chose to invest in solar PV, primarily to reduce their electricity costs and to raise the property value.

Respondent B stated how the financial gains they could receive from the investment due to reduced electricity costs and selling excess electricity was not a reason for the investment, although it was nice to see the cheap electricity bill. Similarly, respondent C did not choose to invest in solar panels for financial gains. Instead, C emphasized how their property was a multi-generational farm, and solar panels was a way to reinvest money into the farm for their children and future generations. Therefore, it can be seen as a financial motive, although not as pronounced as respondent A.

Financial topics were also found in the secondary data collection. Among others, respondent 65 mentioned how the profit of electricity production was one of two considerations they had before adopting, the other consideration being elaborated on under the *household synergies* theme.

Environmental

Respondents expressed a strong motivation to adopt solar PV driven by environmental concerns, particularly the desire to reduce carbon footprints and contribute to a sustainable future society. The extent of the respondents' motivation stemming from environmental concerns did, however, vary. While respondent A chose to invest in solar panels for the financial gains, environmental concern was mentioned to have a minor impact on the decision. For A, reducing the household's carbon footprint was positive, but not crucial. This is contrasted by respondent B, who stated that they cared less about the financial benefits but since they could comfortably afford the investment they wanted to positively contribute to the environment. Therefore, B was driven more by environmental concern although B stressed how they still burn firewood and go on vacations which they know has a negative impact on pollution and global emissions.

Environmental concern was most explicitly mentioned as the primary enabler to adoption of residential solar PV by respondents F and G. They were both highly concerned for the future and wanted to contribute with what they could. Respondent F further emphasized how they had changed their lifestyle to not contribute to overconsumption, aiming to live comfortably while still having a sustainable consumption.

Environmental concern was also identified as an enabler to adoption of residential solar PV among the survey responses, for example by respondent 133 who stated that the environmental benefit of solar PV was the most important factor for their household.

Social

In general, most of the respondents mentioned not being greatly influenced by others in their adoption process. However, the majority of them mentioned how neighbors and friends had been curious of their solar PV system and come to them for information and advice, and later adopted residential solar PV themselves. For example, after respondent C installed their solar panels, four others in the area as well as some friends in other areas of the country have adopted the technology after talking to C. A similar statement was made by respondent D, where they knew their "roof was responsible for two other systems in the area".

Out of all respondents, only C and G mentioned having been influenced by peers to adopt solar PV. This shows how, although the respondents themselves were generally not socially influenced into adopting solar PV, others in their proximity were influenced by them. Therefore, while social influence might not have enabled adoption for most of the study's respondents, social influence is still an enabler to adoption.

Technology interest
Several respondents expressed fascination and interest in solar PV technology, although it was rarely mentioned to have guided their decision to adopt residential solar PV. However, two outliers among the respondents were identified, B and D.

Respondent B had previously installed old solar panels used for heating water in the 1990's and had a clear interest in technologies using solar power. B claimed that they would watch the temperature of the water from the old solar panels and be excited when it reached above 100°C. Similarly, B would enthusiastically follow the curve of generated electricity throughout the day and claimed that having solar panels was fun and exciting. Respondent D also showed great interest in the technology, having followed the technology development from the early 2000's while working in with environmental questions. Other respondents mentioned how they found solar PV fascinating but made no connection to their fascination being a reason to adopt

Energy independence
From the interviews it become clear that energy independence still is an enabler to adoption of residential solar PV, due to a desire of wanting to be less dependent on energy actors and politicians and be less affected by external events. This was exemplified by respondent G adopting solar panels during the summer of 2021 after Russia's invasion of Ukraine and the subsequent increased cost for electricity, and respondent A not agreeing with the shutdown of nuclear plants and instead choosing to produce much of their own electricity.

Household synergies
During the data collection, it was found how synergies between residential solar PV and other factors related to the household. To encompass these synergies, the enabler *household synergies* has been constructed.

One such factor is EVs. Driving an EV was identified as an enabler to adoption in many interviews, and it connects to several of the other identified themes. For example, respondent C mentioned that their household has two EVs and the possibility to charge them for free with their own produced electricity was a nice addition to the other benefits solar PV provides. This was also mentioned by D and G, further proving how having EVs increases the financial benefit of residential adoption solar PV, creating synergy between the systems.

The synergy between EVs and solar PV was also seen to be connected to the environmental enablers as both respondent C and D wanted to not only charge their EVs for free, but also using clean energy whereby solar PV was an appealing investment. This further connects to the theme of energy independence as C and D both explicitly stated wanting to power their vehicles with their own energy and be less reliant on energy actors. The finding of EVs creating an enabler to adoption of residential solar PV was also found in the secondary data, where respondent 164 mentioned how the decision to install solar PV was made after having bought their first EV.

Another synergy was found between residential solar PV and property characteristics. The possibility of a great location for solar panels was stated by respondent C to have been the main enabler to adoption. As C had a barn with no objects obscuring the sun and a south-facing roof, the decision to invest in solar PV seemed like an easy choice and a great way to reinvest money into the farm.

For respondent D, property characteristics served as both enabler and barrier. D's roof was old and to install solar panels would not be financially viable as it would have to get replaced. Once the roof was changed, D instantly installed solar panels and adopted solar PV. Therefore, changing the roof was the main enabler for adoption. Another enabler related to this topic was mentioned by respondent 65. They stated how covering the south-facing roof would provide shading during warm summer days, lowering the indoor temperature. While other respondents have mentioned how they had an appropriate roof for the solar panels, it was generally not mentioned as a contributing factor for the decision to adopt in their cases.

4.2. Current barriers to adoption of residential solar PV

The enablers to adoption identified in the qualitative interviews are summarized in the following table and presented separately in their respective sections.

Barrier	**Reason**
Financial	Installation cost
Administrative	Unclear regulations, contact with several actors
Lack of information	Unprofessional suppliers, misinformation
Property characteristics	Unsuitable roof

Table 6. Summary of barriers to adoption of residential solar PV.

Financial

Although all respondents mentioned how installing solar panels was a significant investment, it was generally not seen as a barrier. Many of the respondents, among others respondent C, further explained that while the subsidy they were to receive was nice, it had no effect on the decision to install solar panels. The investment was somewhat of a barrier for respondents E and G, who stated that they wanted to install solar panels earlier but chose not to as they had other renovations to prioritize and could not justify the investment without more savings.

Administrative

As the respondents needed to contact different governmental actors and institutions in order to get approval and connection to the grid, some time was spent during before and during the installation process to get the system working. Respondent A mentioned how the regulations from Energimyndigheten were unnecessarily unclear and difficult to understand, which was supported by respondent D. However, all interview respondents stated that the administrative barriers were not significant during their installation processes.

Contrarily, several respondents to the survey mentioned having trouble with the grid actor Vattenfall. For example, respondent 18 mentioned how Vattenfall's communication was poor and respondent 96 stated how the installation of the electric meter stalled for six months, delaying the time for the system to generate power.

Another administrative barrier could be seen during the interview with respondent B as they mentioned how houses new neighborhood in their municipality were required to have red roofs, meaning that solar panels are not allowed to be installed as the dark panels would block the red tiles. Therefore, although this did not affect B who lived on the countryside, municipalities can be seen to administratively hinder households from adopting solar PV and hence create a barrier to adoption.

Lack of information

A lack of information from suppliers was indirectly mentioned by the majority of respondents, with respondent A mentioning how some of the suppliers were not serious enough about the installation and seemed more concerned with finding an easy sale. Respondent A therefore scouted several suppliers and chose the supplier who came to the property and inspected the roof, which gave them more credibility. Respondent D gave a similar response, where several suppliers were scouted, one of which seemed extra professional.

During the interview with respondent C, they mentioned how even though they found little issue regarding supplier they knew of other adopters who were not as lucky. C suspected the other adopters had not been properly informed of how the direction and angle of the roof would affect the electricity production and were therefore not as satisfied with their supplier and solar PV system. A similar mention was made by respondent D, as their chosen supplier stated how the subsidy program might be unapplicable for their system as it was to be removed. Other suppliers D had contacted did not give this information, which could have resulted in D feeling misled and not giving positive recommendations for others in their neighborhood.

Property characteristics

Property characteristics being a barrier to adoption of residential solar PV was only explicitly identified in the interview with respondent D. As mentioned, when changing the roof D instantly installed solar panels which is why it was their main enablers. However, D also stated how this was the main barrier to adoption as D had pondered installing solar panels already in 2005 but waited until 2020 as the roof was old and needed to be changed before installation.

5. Analysis

This analysis integrates the empirical findings with the theoretical background using the framework presented in chapter 2.3. To encapsulate the enablers and barriers to adoption of residential solar PV, different aspects of residential solar PV are used as basis for the analysis. Within these aspects, enablers and barriers take different shapes and can be connected to elements of the theoretical models and the case studies used to identify the previous enablers and barriers to adoption. The different aspects of residential solar PV used are electricity production and consumption, installation and usage, social, and institutional and infrastructural support. Last follows a subchapter on general sensemaking during the adoption process of residential solar PV.

Electricity production and consumption was used to analyze mainly the enablers and barriers to adoption of residential solar PV that can be connected to the performance expectancy (Venkatesh et al., 2003) and relative advantage (Rogers, 1983), as these enablers are dependent of the system's output and how the electricity is utilized. The aspect of installation and usage was instead used to analyze how the complexity (Rogers, 1983) and effort expectancy (Venkatesh et al., 2003) influence the enablers and barriers to adoption of residential solar PV. The social aspect of residential solar PV was mostly used to analyze the social enabler, but also other enablers and barriers, by relating them to the social influence determinant (Venkatesh et al., 2003), and sensemaking (Pereira, 2002). Lastly, the aspect of institutional and infrastructural support aids in the analysis of facilitating conditions and how these influence the enablers and barriers to adoption of residential solar PV. By analyzing these different aspects of residential solar PV a deeper understanding of the enablers and barriers to adoption is reached, but also an understanding of how they influence each other.

How the enablers and barriers can be connected to different aspects of residential solar PV is illustrated in figure 2 and 3 below, where an X signifies a connection.

	Enablers					
Aspects	Financial	Environmental	Social	Technology interest	Energy independence	Household synergies
Energy production and consumption	X	X			X	X
Installation and usage				X		
Social	X	X	X			
Institutional and infrastrutural support	X					X

Figure 2. Connections between enablers to adoption of residential solar PV and aspects of residential solar PV.

	Barriers			
Aspects	Financial	Administrative	Lack of information	Property characteristics
Energy production and consumption				X
Installation and usage		X	X	
Social		X	X	
Institutional and infrastrutural support	X	X	X	

Figure 3. Connections between barriers to adoption of residential solar PV and aspects of residential solar PV.

5.1. Electricity production and consumption

The first aspect of residential solar PV to be analyzed is the electricity production and electricity consumption as the performance of the system is dependent on how much electricity the system produces and how it can be used. The financial enablers to adoption of residential solar PV were in the empirical findings mainly connected to reduced electricity costs and potential revenue from selling excess electricity. These enablers are directly related to how much electricity the system produces and how much of the produced electricity is consumed, indicating that the financial enabler is coupled to the performance expectancy (Venkatesh et al., 2003) and relative advantage (Rogers, 1983) of residential solar PV systems.

Early studies indicated that financial benefits existed , albeit weakly, as the cost of residential solar PV significantly decreased the financial appeal (J. Palm & Tengvard, 2011). Over time, as installation costs decreased, the financial appeal of solar PV increased (J. Palm, 2018). This evolution seems to have continued as financial enablers are identified to be even more prominent now, with financial gain being a primary enabler for many interviewed households and respondents generally stating how the installation cost was not an issue. While the development can be partly explained by technological advancements and geopolitical changes having made solar PV more accessible and cost-effective, other factors have been found to further enhance the performance expectancy (Venkatesh et al., 2003) and relative advantage (Rogers, 1983).

Producing clean energy through solar PV is not only cost-effective but also more environmentally friendly than many other energy sources, reducing reliance on fossil fuels and decreasing carbon footprints. Similarly to the financial enabler, the magnitude of the environmental benefit depends on how much of the adopter's and society's use of fossil fuels can be reduced using the solar PV system and is therefore also related to the system's electricity production and consumption. This shows how the strength of both the financial and environmental enablers is connected to the performance expectancy (Venkatesh et al., 2003) and relative advantage (Rogers, 1983) of residential solar PV. Furthermore, as many households adopted due to both financial and environmental reasons, the benefit of both financial gain and environmental impact amplifies the relative advantage and performance expectancy of solar PV even further.

Other enablers found in the empirical findings to enhance the performance expectancy and relative advantage of residential solar PV are household synergies. One such synergy are the property characteristics, such as roof orientation, size, and shading. This synergy influences the performance expectancy and relative advantage of solar PV systems by increasing the system output. In turn this leads to increased financial and environmental benefit as more clean energy can be used or sold.

The other synergy found to enable adoption of residential solar PV is the synergy between EVs and solar PV systems. It was found that EVs are a good use for the produced electricity as they not only charge for free at home, but also reduce the overall carbon emissions. Similarly to property characteristics, this increases the financial and environmental benefit by enhancing the performance expectancy and relative advantage. The combination of solar PV and EVs therefore creates a connected green energy solution, making the adoption of both technologies more attractive. The performance expectancy and relative advantage of residential solar PV is thus not limited to electricity production for home use but extends to sustainable transportation, adding another dimension to the perceived benefits.

Lastly, by producing electricity through residential solar PV, adopters become less reliant on energy actors and Sweden's and Europe's energy supply. Energy independence was previously identified as an enabler to adoption of residential solar PV (Bergek & Mignon, 2017; J. Palm, 2018), and continues to be so according to the empirical findings. This enabler can be related to the financial enablers to adoption of residential solar PV as adopters want to be less affected by supply issues resulting in an increased cost for electricity. Therefore, the different enablers found to increase the performance expectancy of residential solar PV can also be found to improve adopters' independence.

5.2. Installation and usage

The second aspect of residential solar PV to analyze is the installation and usage, and how these aspects relate to the previous and current enablers and barriers, as well as the theoretical models.

Previous studies noted that a lack of clear information created a barrier to adoption of residential solar PV (Bergek & Mignon, 2017; J. Palm, 2018). This barrier is still relevant as several respondents have needed to contact multiple suppliers in order to find a professional actor, with some actors even giving overly hopeful and potentially false information regarding system performance to get sales. This increases the complexity of the knowledge and persuasion processes (Rogers, 1983), and therefore the effort expectancy (Venkatesh et al., 2003) as more effort is required by potential adopters for a successful installation.

It is not only gathering information about suppliers and solar PV in general that requires effort. Respondents have stated how regulations could be difficult to understand and how getting in contact with grid actors was a slow process. These administrative barriers have also been identified previously (J. Palm, 2018) and while some respondents mentioned how their solar PV installer handled most of the application processes, it can still be found in many adoption cases. The administrative barriers therefore further increase the complexity and effort required for installation.

However, despite the effort required during the knowledge and persuasion stages, once the solar PV system has been installed and connected, it was found to require little to no effort to produce electricity. This enables adoption of residential solar PV, since if one is either lucky enough to find a professional supplier or prepared to exert the required effort, the ease-of-use (Venkatesh et al., 2003) is very high. It can therefore be said that the barriers stemming from a lack of information and administrative hurdles negatively impact the ease-of-installation and first two stages of the adoption process. If these barriers were to be overcome or diminished, the complexity of residential solar PV is expected to not contribute to much resistance towards adoption.

5.3. Social

The third aspect which is influenced by various enabler and barriers to adoption of residential solar PV, and therefore of interest to analyze, is the social aspect. This relates to how each household's social status and influence can enable adoption for others in their proximity, but also how societal norms can influence households.

While it was found in previous studies that residential solar PV was sometimes adopted as way of increasing one's social status and exert influence over others (J. Palm & Tengvard, 2011; J. Palm, 2018), this was not necessarily found in the empirical data of this study. However, although many respondents stated they had not been influenced by others to adopt solar PV, it is clear that social influence is still an enabler to adoption as many respondents noted that their adoption of solar PV led neighbors and friends to do the same. This finding aligns with the social influence determinant (Venkatesh et al., 2003) and the observability attribute (Rogers, 1983), where the visible success of adopters provides credibility and encourages others to follow suit.

The social factors are also closely linked to several other enablers of residential solar PV adoption. With environmental concerns and climate change becoming more prominent in the media landscape, societal pressure to adopt green technologies is enhanced. Furthermore, the social aspect also interacts with the perceived complexity (Rogers, 1983), and performance and effort expectancy (Venkatesh et al., 2003) of the technology. Adopters who share their positive experiences can demystify the technology for others, reducing perceived complexity and effort expectancy while increasing the performance expectancy. This social learning process can stimulate adoption, as indicated by respondents who influenced their peers through their own adoption. However, the opposite can also be expected to be true. If an adopter has had a negative experience with a supplier or their system in general, this can lead to others perceiving effort expectancy and complexity to be higher, while reducing the performance expectancy. This will then inhibit adoption of residential solar PV, stressing the importance of positive social influence.

5.4. Institutional and infrastructural support

A final aspect of residential solar PV is the institutional and infrastructural support for the technology. Previous studies identified the impact of policy changes and administrative barriers on adoption (Mundaca & Samahita, 2020; J. Palm, 2018). The findings from respondents in this study reflect some of these earlier insights, emphasizing the need for clear and supportive regulatory frameworks to enhance the facilitating conditions (Venkatesh et al., 2003). This would simplify the adoption process by reducing the complexity and effort expectancy previously mentioned to negatively impact the installation of residential solar PV. However, in this study it was also found that some aspects of institutional support are of less importance now compared to previously. Subsidies have previously been seen as an important enabler to adoption (Mundaca & Samahita, 2020). On the contrary, the respondents to this study stated how the subsidy or tax relief had little to no impact on their decision. This indicates that the facilitating condition of subsidies or tax reliefs are of less importance now, potentially due reduced installation cost having weakened financial barrier.

Facilitating conditions are, however, still highly important for the adoption rate of residential solar PV to increase. As mentioned, simplifying the administrative processes can reduce the effort expectancy and complexity, making the adoption process easier to navigate and quicker. Furthermore, while subsidies and tax reliefs are deemed less important in this study, they do directly improve the financial attractiveness of solar PV. This can be a relevant enabler for potential adopters with less financial resources where the expected performance of the solar PV system on its own is not enough to justify the installation cost.

Lastly, institutional and infrastructural support for EVs, which were found to create a positive synergy with solar PV, can in turn also facilitate adoption of residential solar PV. By supporting the transition towards electrified transportation, the compatibility of values driving EV adoption and solar PV adoption can reinforce each other. Furthermore, facilitating conditions that improve the relative advantage of EVs in Sweden, such as increased cost for fossil-fuels or zones where vehicles driven by combustion engines are banned, can potentially improve the performance expectancy of solar PV and strengthen the enablers related to system performance.

5.5. General sensemaking across all aspects

Throughout the adoption process and when internally assessing the aspects of residential solar PV, adopters and potential adopters make sense of the innovation in an effort to better understand how it could benefit them (Pereira, 2002). During this sensemaking, past experiences influence the perception of residential solar PV and can potentially lead to a decision to adopt. For example, it was found that a long interest in solar technology and previous positive experiences with solar water heating systems played a significant role in the decision to adopt solar PV for some respondents.

Furthermore, the social interactions mentioned in chapter 5.3 where neighbors and friends asked questions about an adopter's residential solar PV system are themselves acts of sensemaking. As previously stated, positive experiences shared by adopters can serve as benchmarks for others, reducing the perceived complexity and effort expectancy while increasing the performance expectancy. This iterative process, where past experiences from adopters inform future decisions and potential adopters, underscores the dynamic nature of solar PV adoption and the importance of sensemaking.

6. Discussion

In this chapter, the analysis of the enablers and barriers to adoption of residential solar PV in Sweden is discussed in relation to the study's purpose and research questions. Following the implications of the study, considerations for future research is presented to emphasize relatively unexplored areas of residential solar PV adoption.

6.1. Implications

To answer the research questions of the study and fulfill the purpose, the first research question regarding the evolution of enablers to adoption of residential solar PV in Sweden is combined with the third research question regarding what can explain the differences between current and previous enablers. The second research question is answered in a similar manner.

6.1.1. Evolution of enablers to adoption of residential solar PV in Sweden

It is clear that financial and environmental enablers are still the primary enablers to adoption of residential solar PV. Furthermore, the financial enablers have strengthened as a result of increased electricity costs and the ability to sell excess electricity to the power grid. The increased electricity costs have improved the performance expectancy and relative advantage of residential solar PV and can partly be explained by Russia's invasion of Ukraine disturbing Europe's energy supply and the shutdown of nuclear plants in Sweden. A new finding related to the financial enabler of residential solar PV is that contrarily to previous studies (Mundaca & Samahita, 2020), government policies such as subsidies and tax reliefs have not had much influence in the adoption decision. Regarding the environmental enabler, climate change has grown more apparent and environmental consciousness in Sweden has increased. This is suspected to have strengthened the environmental enabler to adoption of residential solar PV as the relative advantage of solar PV and RETs compared to non-renewable and non-sustainable energy sources grows.

Furthermore, these two enablers have been enhanced by a new enabler: the synergy between residential solar PV and EVs. By having residential solar PV, EVs can be charged for free at home, maximizing the system use. This increases the relative advantage of residential solar PV further and strengthens both the financial and environmental enablers as it is both cost-efficient to charge at home and the environmental values connected to having both residential solar PV and EVs are compatible.

The social enablers are deeply intertwined with the increased environmental awareness and while this study found few respondents to have been influenced by peers in their decision to adopt, society's increased pressure on sustainability can be assumed to have influenced the adoption of residential solar PV, as well as other RETs. It was also found that social influence is an enabler as several respondents saw peers adopting residential solar PV after seeing their successful implementation. This finding shows the importance of observability for adoption as the solar panels being visible stimulated discussion and learning about the technology. During these discussions in the knowledge and persuasion stage, sensemaking allows potential adopters to contextualize residential solar PV and create their own perceptions about the technology, further emphasizing the individual beliefs and values in the adoption process.

Technology interest as an enabler to adoption of residential solar PV, while prevalent, was not identified to have a great influence on the adoption rate. This can indicate how technology interest becomes less important as adoption continues, in line with Rogers' (1983) notion of later adopters having less technology interest than early adopters and innovators. However, this study has not evaluated what adopter categories the current adopters of residential solar PV belong to, and a definitive conclusion is therefore not possible.

The enabler of energy independence, while separate, is also deeply connected to other enablers. By having both residential solar PV and EVs, households can become less reliant on fossil fuels and energy actors. This is also found to be a relative advantage of residential solar PV, further enhancing the performance expectancy. Becoming less reliant on centralized energy production has also been shown to enable adoption of residential solar PV after Russia's invasion, arching back to the discussion of financial enablers.

6.1.2. Evolution of barriers to adoption of residential solar PV in Sweden

Regarding the evolution of barriers to adoption of residential solar PV, many similarities can be found between the findings of this study and previous studies. Lack of information, which was identified by both Bergek & Mignon (2017) and J. Palm (2018), still delays adoption as potential adopters need to scout for professional suppliers which increases the effort expectancy on adoption of residential solar PV. Administrative hurdles were also identified by both Bergek & Mignon (2017) and J. Palm (2018) and can still be found as a barrier delaying the adoption of residential solar PV. Confusing regulations and several application processes for the system to be fully operational increases the complexity and effort expectancy of adoption of residential solar PV further. This can be mitigated by improving the facilitating conditions with better institutional support to simplify the installation and application processes.

A barrier not mentioned in the previous case studies (Bergek & Mignon, 2017; Mundaca & Samahita, 2020; J. Palm & Tengvard, 2011; J. Palm, 2018) is how the property characteristics can impede adoption. If the roof's state or orientation is sub-optimal for residential solar PV, the relative advantage diminishes and lowers the performance expectancy. In turn, this negatively impacts the enablers to adoption related to system performance and hinders adoption. Although this barrier can be assumed to have hindered adoption also previously, it shows how residential solar PV is not a solution for all households.

Lastly, J. Palm (2018) noted how the financial aspect of residential solar PV had slightly shifted from being a barrier to an enabler to adoption. This study confirms the finding and concludes that the evolution has continued in the same direction. As a result of decreased cost, the financial barrier has weakened, further enhancing the relative advantage of residential solar PV, and subsidies or tax reliefs appear to no longer significantly impact the adoption decision.

6.2. Considerations for future research

This study has not quantitatively evaluated the significance of the various enablers and barriers to adoption of residential solar PV. It could therefore be of interest for future research to measure how influential these enablers and barriers are, to provide an even deeper understanding of what drives or hinders the adoption of residential solar PV. Furthermore, it is of interest to better understand where in the adoption curve residential solar PV in Sweden is situated, as it could lead to better predictions of future adoption rate and lead to more targeted efforts aiming to increase adoption.

7. Conclusions

The purpose of the study was to understand how the enablers and barriers to adoption of residential solar PV systems for Swedish households have evolved since 2018 and what has led to the changes. To fulfill the purpose, a qualitative case study has been conducted where empirical findings of the study have been compared to findings from previous case studies and connected to three different theoretical models for innovation adoption. To gain insights regarding the current enablers to adoption of residential solar PV in Sweden, interviews have been conducted with households who adopted the technology between 2020 and 2024 and triangulated using secondary data from free-text answers to a survey on residential solar PV. This led to the following three research questions being answered: "*How have the enablers to adoption of residential solar PV in Sweden evolved since 2018?", "How have the barriers to adoption of residential solar PV in Sweden evolved since 2018?",* and "*What can explain the differences between the current and previous enablers and barriers to adoption of residential solar PV in Sweden?".*

It has been concluded that financial and environmental enablers to adoption of residential solar PV are still primary, with financial enablers being enhanced by increasing electricity costs. Furthermore, the synergy between residential solar PV and EVs has been found to increase the value of residential solar PV, as it increases the relative advantage of the technology. Connected to these enablers, energy independence has become increasingly desirable as a result of unstable energy supply and increasing electricity costs. Simultaneously, technology interest appears to be a weaker, yet still present, enabler to adoption. Overarching these enablers, social interactions and the shift in societal norms toward sustainability have increased environmental awareness and enabled further adoption of residential solar PV in Sweden. It has also been shown how the enablers to adoption of residential solar PV are interdependent and can influence each other in different ways, for example by household synergies increasing the financial and environmental benefit and strengthening the financial and environmental enablers.

The barriers to adoption of residential solar PV in Sweden remain largely the same as previously, although the financial barrier has weakened due to decreased installation costs. This has led to subsidies and tax reliefs becoming less important for potential adopters with enough financial resources to justify the investment. A lack of information and administrative barriers are still present and increase the complexity and effort required to install solar PV for Swedish households. Better institutional support through clearer communication regarding regulations and solar PV system performance can reduce these barriers by simplifying the adoption process.

The study has thus provided insights as to why households adopt residential solar PV and how the adoption process can be impeded by different barriers. This increases the understanding of why adoption of residential solar PV in Sweden has occurred in the past six years, and the problems adopters have faced.

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Appendix A

The interview guide for the semi-structured interviews is presented below.

Background information
When did you install your solar panels? When did you start thinking about installing solar panels? - What is the reason for the gap between thinking about installing and installing? Why did you start thinking about installing solar panels? Had anyone you know installed solar panels before you?
Positive factors
What were the most important factors leading to your decision to install solar panels? - How did financial aspects influence your decision and what considerations did you have? - How did environmental aspects influence your decision? - Did any recent events or changes influence your decision? Did any specific incentives influence your decision? - How important was the subsidy or tax relief for your decision? Have you experienced any positive results from your installation and how have you shared this with others?
Negative factors
Was there anything that made you feel uncertain of installing solar panels and why? - How did the cost of the system influence your thought process? - Did discussions with other solar panel owners make you hesitant and if so, how? Were there any delays to the installation process and if so, why? - What was your experience with regulations, applications, and various actors? Have you experienced any problems with your solar panels that you have discussed with others?
Additional comments
Is there anything you would like to add which has not been discussed in this interview?

Table A. Interview guide used as basis for semi-structured interviews.

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
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