A Systems Approach to Supply-Demand Interactions in Norway: A Case for the Recent Growth in Rooftop Photovoltaic Panels Investments

By

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Thesis submitted in partial fulfilment of the requirements of Master of Philosophy in System Dynamics (Universitetet i Bergen)

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December 2022

Acknowledgement

December 2022

First of all, I would like to thank Birgit, my supervisor, for your guidance and support throughout the process of writing my thesis. Your insights and expertise have been invaluable to me, and I am grateful for the opportunity of your supervision.

I also want to express my gratitude to my friends and family, especially over the past month as I have worked to complete this project. Your encouragement and understanding have meant a lot to me, and I couldn't have done it without support. Unfortunately, the holiday season has not been the most convenient time to be finishing up the project, but I am grateful for the understanding of my brain only being partially in attendance when we have met.

Lastly, I want to thank myself for persevering in the completion of the thesis. It's been a very busy semester, and I am proud to say I have survived.

On to new adventures!

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Abstract

Adoption of solar panels in Norway has been driven by various factors ranging from the economic benefit from adoption, motivation for self-sufficiency, knowledge of the performance of PV and the perceived environmental performance. This has been widely reported in academic literature and confirmed in observations of non-adopter, potential adopters and adopters in comment sections in social media. Yet, the adoption of solar panels is currently constrained by the supply-side of solar panels. The limited availability of solar panels due to supply chain issues and the availability of skilled installers have reported to constrain adoption. Using system dynamics modelling, two policies have been tested in order to address these constraints: a hiring policy and an inventory policy, consisting of recycling and reusing solar panels. The results of these policies conveys that the hiring policy is not useful in the BAU scenario, because there are too few solar panels. However, if the production rate of the producers is more like the desired shipment to Norway, then a hiring policy is more impactful. Overall, the inventory policies were more effective in increasing adoption of solar panels. In the end, the most important insight is that it is not beneficial use of resources of demand-side policies if the capacity of the suppliers is too low. For increased adoption rate, the policies must be on the supply-side.

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Chapter 1 INTRODUCTION

Solar panels have been a source of energy since as early as the 1970s. At the time only a supplementary source of energy, it has recently experienced a growth on residential rooftops with a three times growth between 2015 and 2020, and a current surge in investments (Viseth, 2021; Henriksen, 2022). Whereas the first solar panels were not connected to the electrical grid, the most recent customers are connected and function as both a buyer and a producer of energy feeding their surplus into the local power grid. These new customers are called prosumers, locally known as the *Plusskunde.*

Recent studies on the Norwegian prosumer market has described the adopters of solar panels to be mainly middle-aged, high-income men living in detached housing with a higher technical interest and environmental concern than the average user (Lundheim *et al.*, 2021; Dalen, Halvorsen and Larsen, 2022). These are characteristics similar to other countries, for example the UK, where a study of solar panel users found that the prosumers were the older, wealthier and the well-educated homeowners (Islam and Meade, 2013). Adoption of solar panels seem therefore to only be occurring in a small part of the population with a certain socio-economic background. Generally, investing in solar panels is perceived as an expensive and risky affair with economic uncertainties and a cost that might be too high for the average person (Chadwick, Russell-Bennett and Biddle, 2022).

Some policies have been implemented in Norway to stimulate the process of adoption. Enova, a state-owned organization under the Department of Climate and Environment who manages the funds for transition of energy use and production, is the organization in charge of financial support to solar panels in Norway. In 2022, the grant is of a maximum 47 500 NOK in a one-time investments for the technology depending on installed capacity (Enova, 2022), but this does not cover all cost of investments, even with a significant decrease cost of solar panels in the last 16 years. Since 2006, the price per panel has decreased by 60% and it is expected that by 2030 it would have reduced by 40-55% again (Nilsen, 2016b). While the cost is decreasing, it still is a high investment for the average household and considering the adopter need to pay upfront, *then* apply, and lastly receive the grant after the instalment of the panels, there are not all households that could invest.

1.1 Problem Setting

With the historically low supply of energy experienced in 2021-2022 (NVE, 2022a) in Norway coupled with a lower supply of natural gas to Europe after the Russian invasion of Ukraine (Di Bella *et al.*, 2022) has seen a sharp increase in electricity prices (Aam, 2022; Uribe, Mosquera-López and Arenas, 2022). With continued plans to electrifying society, certain parts of Norway possibly experiencing power deficit in a future as near as 2026[1] (Statnett, 2021). Traditionally, Norway has had a high and a relatively constant supply of hydropower and with this enjoyed low electricity prices.

The recent year has seen electricity prices far above what is expected in Norway (NVE, 2022a; Statistisk Sentralbyrå, 2022b). Power connection to other counties in Europe and generally higher gas prices, an indicator of the energy prices (Di Bella *et al.*, 2022; NVE, 2022a; Uribe, Mosquera-López and Arenas, 2022), has seen an unprecedented growth in energy prices. Consequently, many people have examined alternative options to electricity by adopting solar panels, also known as photovoltaic panels, to supplementing their own needs to electricity by becoming what is known as prosumers.

The consequence of this, however, is a high reported demand for solar panels (Rustad, 2022). With supply issues abroad (Pedersen, 2022) have numerous potential customers experienced long waiting times (Engen, 2022), and some suppliers have had to deny customers, having already reached their capacity to supply panels early in the year (Schau, 2022).

1.2 Research Questions

The exact reasons for adoption are varied, complex and consists of social, economic, and cultural. For this reason, the topic of my thesis will be on adoption of solar panels in Norway and the interaction of the adoption decision with the suppliers of panels. The literature on diffusion of solar panels is vast where examples are studies like Islam (2014), Korcaj, Hahnel and Spada (2015), Schaffer and Brun, (2015), Rai, Reeves and Margolis (2016), Heiskanen and Matschoss (2017), Do *et al.* (2020), Lundheim *et al.* (2021) and Hansen, Jacobsen or Gram-Hanssen (2022) to mention a few.

Norway has until recently had a relatively low adoption rate but are currently experiencing a sudden surge in adoptions of solar panels. I want to expand on current literature

[1] Report from *before* the Russian Invasion.

to understand what is occurring now when the adoption rate has risen quite quickly, and the suppliers have issues with capacity to supply its customers. The addition of studying the supply-side of solar panels, can give insights into what policies can increase the capacity and aid low-adoption countries prepare for higher rates of adoption by understanding what is considered impactful choices by the suppliers.

Using system dynamics for diffusion of solar panels is not new (e.g. Kubli (2018); Zapata Riveros, Kubli and Ulli-Beer (2019)), however, I have not found studies using the method with diffusion of solar panels in Norway. Additionally, the supplier side of solar panels do not seem to have as much attention, especially in combination with the demand side of diffusion. While there are studies on the solar market like Bankel and Mignon (2022) focusing on business models from a solar firms perspective, Karakaya, Nuur and Hidalgo (2016) on solar firms surviving decreasing adoption rates, on knowledge spillovers by Nemet *et al.*, (2020), etc. none takes a system approach combining several concepts from the supply of solar panels with the demand-side of diffusion. I therefore propose to add a structure to the model on the supply-side in Norway where the main objective is to explore the supply and demand interactions for rooftop photovoltaic panels in Norway. The main research question is:

What has driven the diffusion of solar panel in Norway and how are the current suppliers managing the current state of solar panel investments?

To answer this question, I will also answer:

- How does the non-adopter, potential adopter and adopter differ?
- Which policies are currently in place, how are they performing and what could be other possible policies?
- What is the role of suppliers in the current market?
- What are the biggest barriers of the suppliers?

1.3 Behaviour over Time

Adoption of solar panels has increased in the last few years. Starting from 2015 with less than 1000 solar prosumers, it has grown to 9000 prosuming households. The growth has been exceptional, yet the adoption is well below the technical potential, said to be 157 Twh (Thorud and Dale, 2020). In 2021, only 0.016% of all energy produced in Norway came from solar energy with a yearly production of 154 Twh (Viseth, 2021). This means only 2.4 Twh of the potential of 157 Twh is produced.

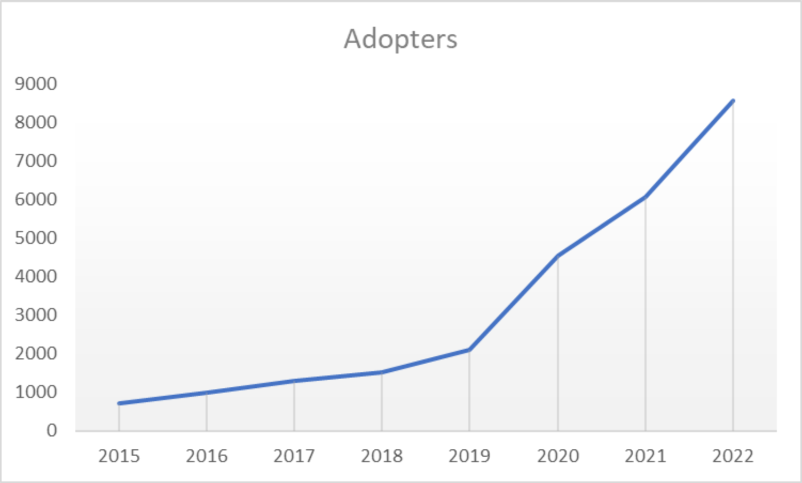

Figure 1.1 – Development of adopters between 2015 and 2022 (NVE, 2022b).

The figure 1.1 above shows the development of adopters between 2015 and 2022. Adopter in this case is defined as the household making the decision to adopt.

The second reference mode is the accumulated installed capacity from adopters of solar panels in Norway. Figure 1.2 below, shows the development over time for capacity.

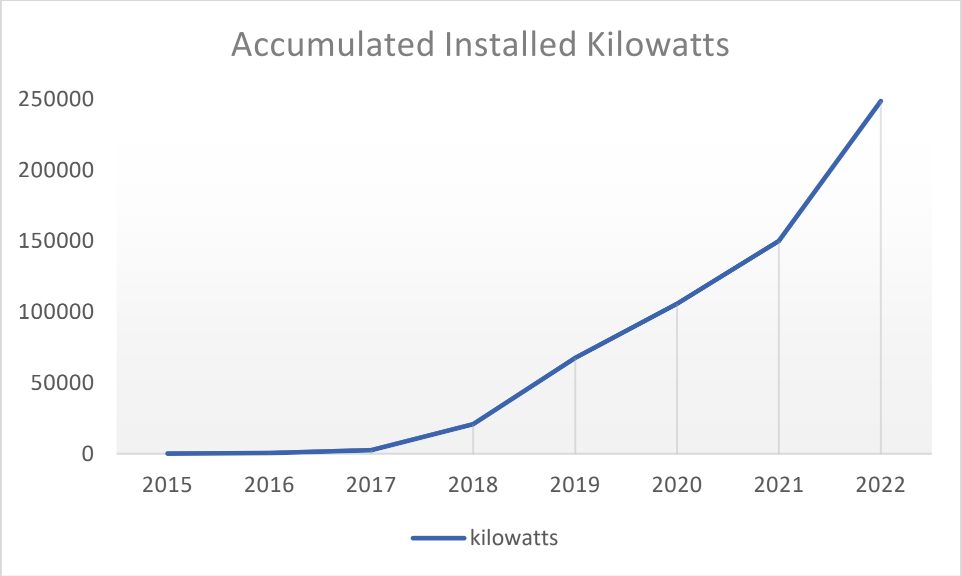

Figure 1.2 – Development of installed capacity between 2015 and 2022 from Elhub Dataset (Øvrebø, 2022).

1.4 Research Outline

In Chapter 1, I have introduced the topic of the thesis, research questions to be answered and the dynamics hypothesis. Further, in Chapter 2, I will discuss the research methodology of the thesis. Chapter 3 explains the model structure of the thesis and is divided into the supply and demand-side of diffusion of solar panels. This chapter is the result of the literature review, interviews, and social media observations. This chapter also discusses model boundaries and main assumptions in the model. In Chapter 4, I state the validation process of built model, and provide the result of said validation tests. In the next chapter, Chapter 5, I continue to the simulation results, while Chapter 6 discusses policy options and reflects on potential issues and implementation. Lastly, in Chapter 7, I will summarize the thesis and fully answer the research questions and conclude the thesis.

Chapter 2 METHODOLOGY

The topic of study in this thesis is the supply and demand of solar panels in Norway between the years 2015 and into the future, ending in 2050. This examines the interaction between demand and supply of solar panels at a time of increased demand. The demand side consists of the drivers of investing in solar panels and suggests a theory for the sudden investment in PV panels after a late start and an initial slow solar market in Norway. The supply side explores the effect of the sudden increase of investments in the last years on business and what might happen in the future.

The thesis uses a mixed-methods approach to answer the research questions asked. It uses interviews, observations and literature for data collection, and system dynamics for analysis. The latter giving opportunities to find and exploit leverage points of the system and further understand the effect of uncertainties. For the modelling, it uses Stella Architect, a modelling software for system dynamics.

The structure of the chapter is as such: section 2.1 discusses the system dynamics method and justifies its use. Section 2.2 states the data collection methods, explaining how it was conducted. Section 2.3 talks about the analysis, while section 2.4 comments on the ethics of the thesis, particularly in the context of the interviews.

2.1 System Dynamics Method

Conducting the analysis of this thesis, I will use system dynamics. The method of system dynamics is useful when studying problems that are dynamic and complex, and when system includes feedback loops and delays (Sterman, 2000). Examining behaviour over time graphs, it is possible to observe what has happened to a variable while giving a theory as to why it occurs like that, for example by examining adopters or the installed capacity, as explained in chapter 1 above. The method also allows for testing different scenarios and uncertainties.

The method will therefore be appropriate due to the complex nature of the drivers of diffusion. The supply-side and the related supply chain of the model adds the possibility of understanding the effects of shocks to the system coupled with the current growth in demand, functioning as a demand-side shock, I will explore the interactions between supply and demand. Further, the system dynamics method allows to explore the effect of feedback loops on diffusion. The decision-making process that affects potential adopters into adopters is several loops, where the communication process of diffusion (word of mouth) itself is a loop affected by the drivers.

System dynamics also considers time delays and nonlinearities in the simulation method. For example, in the supply-side it considers shipping time both from the producer of the solar panels and to the customer. These are significant in the simulation model because different time variables can affect a model considerably if they are wrong or not considered at all. In some systems, the time delay complicates the decision-making process.

Lastly, system dynamics modelling considers nonlinearities in the system. I.e., when several causal factors affect a variable or containing MIN, MAX or graphical functions, and thus affects the variable disproportionately (Mohapatra, 1980; Sterman, 2000). Both can be found in the model.

2.2 Data Collection

2.2.1 Literature Data

An important source of data is literature. To find literature, scientific journals such as Scopus, Emerald Insight and Google scholar has been used. The body of literature incorporates the results of a Boolean search for literature, combining various combinations of search terms such as "PV panels", "solar panels", "drivers of diffusion", "diffusion" and "Norway" for the demand side, while supply side includes additional terms such as "supplier", "installer", "supply chain" and "value chain" etc. Additionally, some academic studies were found in the references of the resulting search or by recommendation.

The included studies had a focus on diffusion of energy technologies, but particularly focusing on solar panels on the demand-side, arguing that the decision-making behind adoption of energy technologies being similar where drivers of diffusion will be similar between the technologies. On the supply-side, however, I have only included studies on the supplier and the supply chain of solar panels. The reasoning being that supply chains or suppliers will differ widely from technology to technology with different experiences.

Not all studies from this literature search were included in the body of literature. I excluded data that did not fit the set inclusion criteria of the thesis. In other words, this means, studies that did not give the information needed like focusing on other topics of solar panels.

Additionally, the thesis particularly focuses on the prosumer population, meaning studies that did not mention connection to the grid was excluded.

In addition to academic literature, I used white papers from governmental and institutional bodies to understand the historical and current development, financial support, and politics of solar panels. The literature includes technical reports from institution like Enova, NVE (Norwegian Water Resources and Energy Directorate), companies like Multiconsult and DNV, and the Norwegian government. News articles about solar panels and prosumers were highly reported over the summer and autumn of 2022 which has been used to understand the current changes in the solar market in Norway, find parameters, and elicit model structure.

2.2.2 Interview Data

Two scoping interviews (N=2) were conducted in October of 2022. Two populations were interviewed: the prosumer (N=1) and supplier (N=1) population. The low numbers of respondents were mainly due to few answering requests for interviews or an inability to participate at the time. I found the interviewees using social media and convenience sampling.

The interviews were semi-structured, permitting for additional questions outside the prepared manuscript when they arose (Luna-Reyes, Diker and Andersen, 2012). The questions were developed to understand the current situation of adoption of solar panels for the supplier, while giving some understanding of the prosumer experience. Based on these topics, I tried to find a balance between too open-ended questions and close-ended questions (see appendix for interview guide). Questions were asked based on what felt natural and where the conversation was going.

Two interview guides were created: one for interviews of the solar panel suppliers and one for the demand side. For the interviews on the supplier-side, there were less literature to base the questions on. The goal then was to find more broad questions to understand the current situation.

2.2.3 Social Media Observational Data

Most observations were recorded in October and November of 2022 in comment section on Twitter and Facebook. Both social medias have several active users with adopters, potential adopters and non-adopters, giving opportunities to observe what narratives are current on solar panels and how the different groups of adopters differ in different groups or comment sections. Comment sections on new articles on solar panel also engages the groups of adopters and gives the opportunity to differentiate the three adopter groups and their drivers.

On Twitter, observations came from searching terms such as “solpanel*er”, “solcelle*r” or similar related terms in the search engine. Tweets about solar panels from either Swedish or Danish prosumers were excluded from the observations. Observations from Facebook came from two sources: interest groups for energy and solar panels and from comment sections on news on the expansion of solar panels. The goal of the observations were to elicit new model structure, in addition to validating literature and model structure.

To ensure quality of observations, I follow Denscombe (2010) chapter 11 on observations. Social media observations may not fall into a typical observation practice with it being written communication rather than real-life events to observe where observations can be made as far back as the researcher is bothered to scroll. That said, the observation type used was closer to participatory observation than systematic observation where me as the researcher also participates on social media, but only to observe and with no communication. The observation method on social media allows for finding people in a natural environment for exchanging opinions.

2.3 Data Analysis

2.3.1 Interview Data Analysis

After interviews were conducted, I made notes of concepts and themes relevant for my topic. From the concept, the focus was to understand what was currently occurring in the solar market and what would be important to include in the model. The purpose of these interviews did not elicit much structure and therefore focused on more on understanding.

2.3.2 Literature Data Analysis

Literature was used to understand how diffusion of solar panels have diffused in society. As with the interview data analysis, themes and concepts were found in the literature. Using literature, I ensured, for example, that the drivers chosen were either statistically significant if a quantitative study or that the conclusion in qualitative studies mentioned this as an important driver to diffusion. Some concepts were more self-evident, like calculating how much income an adopter would receive from their energy production and from that modeling backwards, while other concepts were more diffuse to find structure. In the latter case, the links between each variable are more speculative, but logical.

2.3.3 Social Media Observation Analysis

Using comments from social media comment section, I observed comment sections with the purpose of identifying adopters, potential adopters and non-adopters and their characteristics, and by that building model structure and finding parameters. Observing what was said, who the person would reply to, and the general conversation that ensued, I would determine if they were an adopter, potential adopter or non-adopter, and what attitude or feeling they had about solar panels.

Any observation was noted and coded either as an adopter, potential adopter, or non-adopter and by what driver they mention either explicitly or inexplicitly. By inexplicit, it is more about if the tweeter is positive, negative, or neutral about solar panels. In cases where the relevant tweet is a comment to another tweet, the context is noted, as well. An adopter would be coded as an adopter if they mentioned they were, while showing interest in the adoption of solar panels by others, asking questions or plainly stating intention to adopt would be coded as a potential adopter. The non-adopter, however, was coded by disinterest in or negative view of the technology or whataboutism. From this, I found variables and attempted to build new structure or validate literature.

2.4 Ethics

To avoid any ethical issues that might arise from research, I have followed Denscombe research guide on research ethics (2010) who states that a researcher must take care to not cause any harm to the participants of the study in any way. Careful considerations should be made on the research strategy to avoid any possibilities of harm.

Therefore, per the guide, the participants of the interviews have all voluntarily participated in the research and have at any point had the right to withdraw consent; that is, from before participation until after the interviews have been conducted and analysed. The interviewees have been informed on the topic and scope of the research.

Additionally, the data from the interviews are anonymised, ensuring an interviewees participation is unknown. To add to this, while the topic of research is not particularly controversial, some reflections on the limited group of adopters in Norway have been made and possibilities of recognition from the data provided. I therefore avoid adding any personal information such as age, sex, and location. Recordings made of the interviews has been deleted after use.

For the social media observation, I had a separate sheet for the coding and the internet source, to keep the comment section if I needed to re-visit the comment section, while also ensuring anonymity. The participant is coded, and I never wrote down names or other sensitive information.

The research is reported and accepted in the University of Bergen's project registration system, RETTE.

Chapter 3: MODEL DESCRITPION

Chapter 3 contains the model description based on literature data and data collection coming from interviews and observations on social media. Using these data together, I have built the model structure of diffusion of solar panels and its interaction with the Norwegian Suppliers between 2015 and 2050.

The chapter is structured as such: first, in section 3.1, I introduce the base model which I have expanded upon. Section 3.2 is about the drivers of diffusion. This chapter will examine the different drivers of adoption of solar panels in Norway and has a series of sub-headings with the different drivers. In section 3.3, introduces the drivers from non-adopter to potential adopter coming from observations on social media. Lastly, section 3.4 is about the supply-side model is explained, and gives insights in how the supply and demand is connected in the model.

3.1 Base Model

The basis of the diffusion model is the Acceptance Model from chapter 8 on generic acceptance models (Ulli-Beer, 2013, pg. 198). This model shows how people come to accept or not adopt a behaviour, or in this case, a technology based on the process of changing social norms. The model thus illustrates how potential adopters become adopters; in the context of solar panels adoption in Norway, the model illustrates how a person becomes an adopter of solar panels. While other options of diffusion models exist, like the 1969 Bass Model from Sterman's Business Dynamics (Sterman, 2000, pg. 332), the Acceptance model was chosen because of the model show the process of how internal norms become behaviours of adoption for a population (Ulli-Beer, 2013) as opposed to the Bass Model which, while having similar rationale by social contagion of word of mouth and marketing, is used in the context of the marketing rather than explaining how adopters decides to invest in solar panels.

The acceptance model defines acceptance as the adopter adopting, here solar panels, by the influence of social norms from the environment (Ulli-Beer, 2013, pg. 192). The model (figure 3.1 below) shows the process of changing preferences in society, illustrated by the stocks of the different populations and how these norms are diffused throughout society. In other words, it is a matter of word of mouth, a process frequently cited to be a significant driver of adoption of solar panels (Islam, 2014; Palm, 2016; Mundaca and Samahita, 2020).

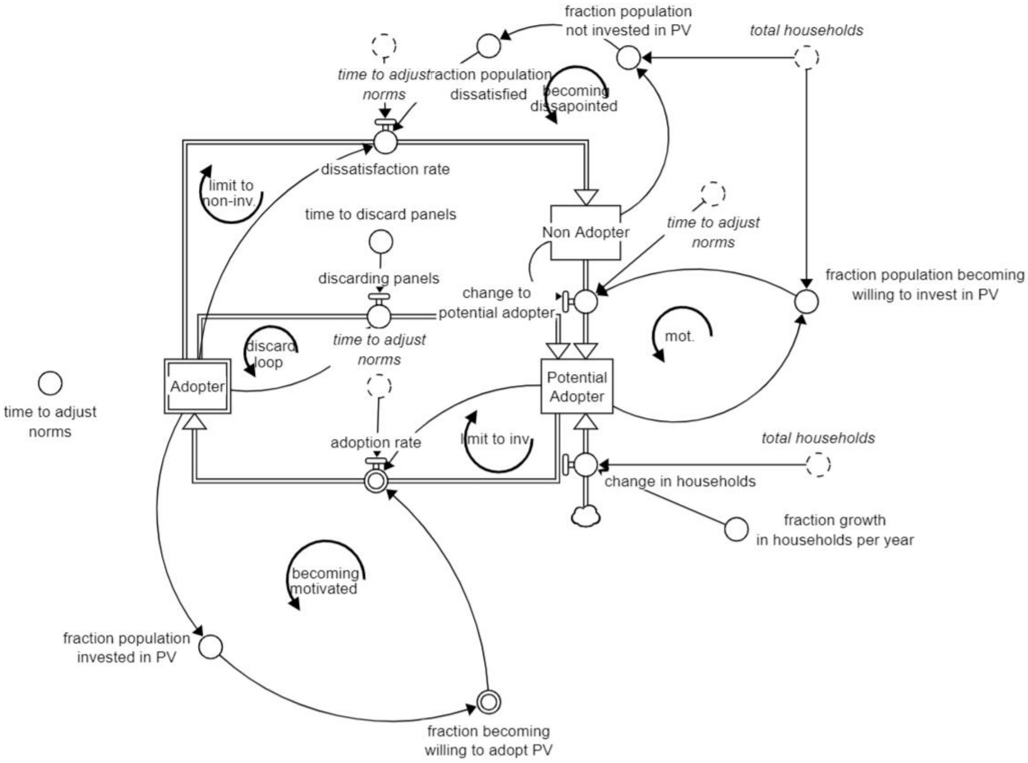

Figure 3.1 – Acceptance model.

The original model has two stocks of non-adopters and adopters that are affected by the norms and behaviours of each other. Added to this base form of the Acceptance model is a potential adopter stock, and an inflow of population growth between the years 2015-2050. The latter inflow addresses one of the weaknesses of many diffusion models which assumes no population growth over the time period.

Therefore, in the model, I differentiate between three accumulating groups of people: the non-adopter, the potential adopter and the adopter which together adds up to the total population of the model. At the core of the model is the movement of adopters from the different stocks. As seen in figure 3.1, the adopter is increased by adoption rate and decreased by the discard rate and dissatisfaction rate of the technology. The discard rate moves people back to the potential adopters, assuming that they will potentially adopt again. An adopter who is dissatisfied, on the other hand, becomes a non-adopter.

For the adoption rate, however, there are some constraints that are not included in the original model. It is constrained by the ability of the supply-side to provide solar panels. This means that, if there are more potential adopters wanting to become adopters of solar than the supply-side can take, only the same number of potential adopters as the supply-side constraint become actual adopters. In other words, the flow is constrained and always equal to the constrain or less. This shows a bottleneck situation in the solar market.

3.2 Demand-Side: Adopter Drivers

Several loops affect the demand for solar panels. The previous section explained how people flow between the three population stocks.

3.2.1 Capacity and Economic Benefit

The adoption rate decides the accumulation of capacity (measured in kw). New adopters per year buys on average between 16-20 panels with an median capacity of 10 (Dalen, Halvorsen and Larsen, 2022). Based on this, the overall capacity increases the inflow of new capacity. However, the panels will normally last between 25-40 years. This outflow decreases the capacity as panels depreciate.

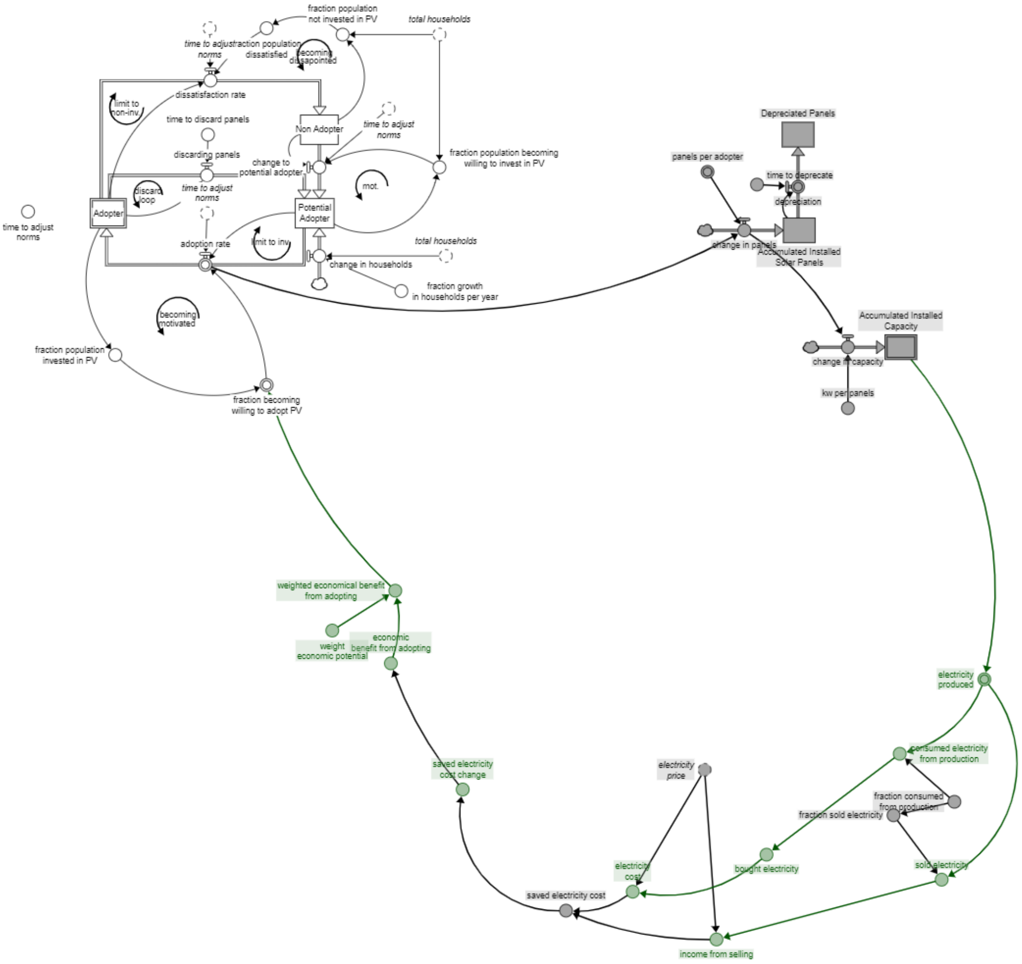

Figure 3.2 Capacity and Economic Benefit.

Based on this, adopters will produce energy. Energy is calculated from the capacity of the whole adopter population multiplied with the peak hours per year. As adopters produces energy, they will either consume or sell the energy, and then buy the rest of the energy based on their needs. What is sold, bought, or used depends on several factors and differs for each season, but in the model, it is formulated as fraction consumed from production and fraction sold electricity. Bought energy thus becomes what is left needed subtracting self-consumption of own production from the total consumption.

In figure 3.2 is the addition of the economical adoption loop. A potential adopter will judge if adopting solar is advantageous to them by the benefits of investing to the cost of the investments in solar panels. This is discussion would often be found in comments sections on news articles about solar panels with questions about if investing would be too expensive compared to the economic benefit of adopting or if the price offered by a company is too high. The latter question is often observed in Facebook groups concerning solar panels production.

If the potential adopter finds the price of the investment too high, they may not be able to invest (Islam, 2014; Karakaya and Sriwannawit, 2015). This, however, depends on the characteristics of the adopter, as studies have found that some adopters are less concerned with the price and more interested in the technology in itself, the environment or both (Islam, 2014; Mundaca and Samahita, 2020; Niamir *et al.*, 2020; Lundheim *et al.*, 2021). This could perhaps be attributed to the earlier adopters and among those, the prosumer interviewee, who were more interested in the technology and advertising the possibilities of usage of solar panels, more than income.

Nonetheless, for the economically driven adopters, this benefit is and will be important in their decision-making as the economical motivation often come from the want to have an income from solar panels and also protect potentially rising costs of electricity (Balcombe, Rigby and Azapagic, 2014). But economic benefit is not only calculated by what an adopter can save from adopting per year. The economic benefit from the income as an adopter is conceptualized as the change in income over time, essentially meaning that as income either increases or decreases, the potential adopters will perceive the income change as positive or negative.

3.2.2 Investment Price

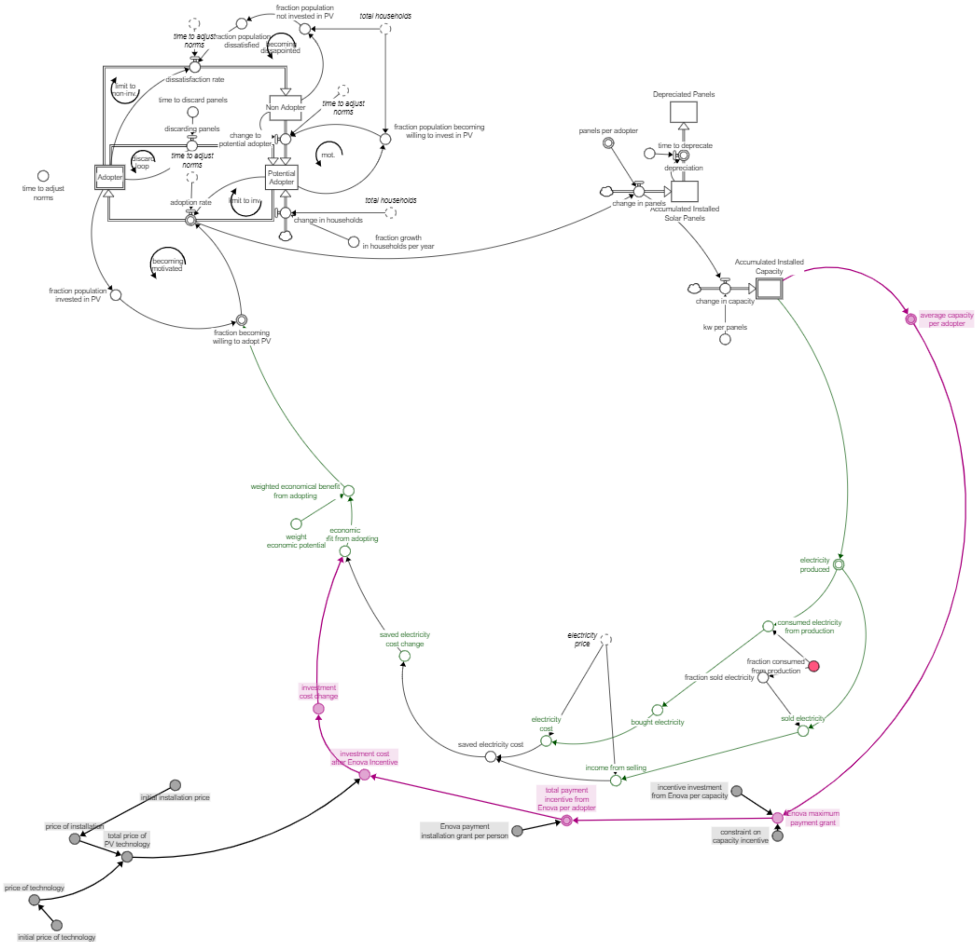

Figure 3.3 – Price of Investment Loops.

The investment price illustrated in figure 3.3 is, as mentioned, one factor affecting the economic benefit. In Norway, the cost of solar panels can be quite high, including the cost of instalment and the technology itself. This cost is frequently reported to be one of the barriers for potential adopters (Karakaya and Sriwannawit, 2015).The high cost of investment is also widely discussed in comment sections. The investment is perceived as quite risky and might not pay back what they want. On a comment section about how much a family saved from adopting, commenters would show distrust of the adopter and blaming them for not mentioning the investment cost as it is so high.

Some of the investments are reduced by the Enova grant, which aids the adopter in investing in solar panels by a fixed installation grant and a variable grant depending on how much capacity is installed (Enova, 2022), but this economic help does not cover all. The purpose of this grant was to enable potential adopters to invest in the technology where the adopter pays upfront and is reimbursed, providing they uphold the set criteria (Enova, 2022). The grant is received only *after* the adopter has invested.

The total price of solar technology is divided in two: one part from the price of installation, another from the price of technology; both affected by the supplier-side of the model. Price of installation decreases as installers receive experience and knowledge of installation (Nemet *et al.*, 2020; O'Shaughnessy, 2022). The price of the technology is affected by scarcity of the material and a learning curve for production, where the accumulated production experience decreases the price (Sterman, 2013).

3.2.3 Knowledge of PV performance

An additional loop is the knowledge of the potential of solar panels. This knowledge loop (figure 3.4 below) is related to how well solar panels could potentially work in Norway. The lack of knowledge about panels are often stated to be an important barrier to adoption of solar panels (Balcombe, Rigby and Azapagic, 2014). A common concern and misunderstanding observed on social media platforms is how well the panels performs and whether investing in solar panels are beneficial. While some non-adopter types will reject the idea of solar panels with no thought to it, a potential adopter asks the questions in relevant social media groups (e.g., Facebook groups for solar prosumers), and receive an answer there. Becoming an adopter means learning about the potential of the PV performance, here conceptualized from energy produced, and thus understand how it is possible to use and produce energy. The knowledge stock is assumed to start at 0.5, mainly due to a thriving non-prosumer solar market on cabins.

The knowledge of PV performance also affects the non-adopter. Observing in comment sections on social media, it is clear some people does not know solar panels have potential use in Norway (see coding in appendix). Misinformation about the performance almost always mentioned often commenting on the usefulness in the winter and at night. An adopter has perceived this knowledge about performance and its usefulness, while the potential adopter is perceiving by asking questions. What seem to differentiate the non-adopter from the potential adopter is whether they are willing to ask the question and perceive the answer from adopters.

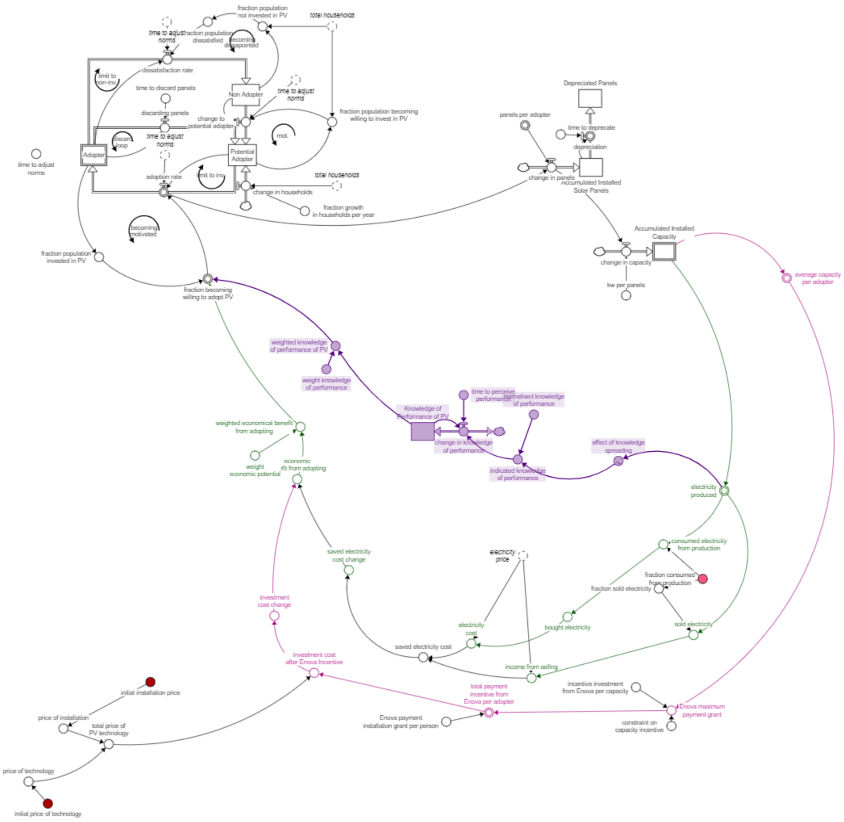

Figure 3.4 – Knowledge of PV performance.

3.2.4 Motivation for Self-Sufficiency

Those who choose to adopt is also driven by the motivation for self-sufficiency (Balcombe, Rigby and Azapagic, 2014; Korcaj, Hahnel and Spada, 2015). Full self-sufficiency is most likely not possible for the average consumer but being able to have some independence from the electricity provider is important for the adopter. In figure 3.5 below, the motivation from self-sufficiency comes from the electricity prices, where a higher price will increase the motivation for self-sufficiency, while lower prices decrease the motivation.

Consequently, electricity prices becomes important in the adoption process which is frequently stated in literature, often citing Long (1993) whose study found that people were more likely to invest on energy conservation technologies when electricity prices rose. This is also a development currently seen in Norway where the adoption rate of solar panels has exploded since the increase of electricity prices since the last few months of 2021. Per the end of 2022, the expectation of adopters is around 11 000 adopters (Øvrebø, 2022).

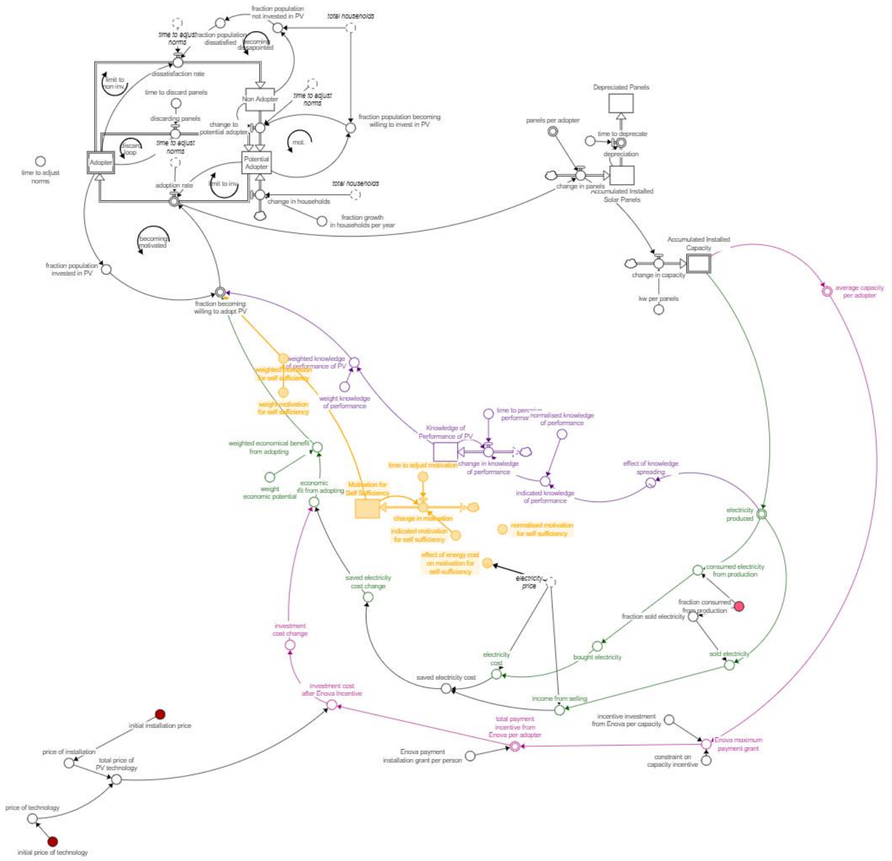

Figure 3.5 – Motivation for self-sufficiency.

3.2.5 Perceived Environmental Performance

While somewhat contested by some studies, can the average adopter be described as environmentally aware. Some studies have pointed to an importance in the economic benefits where the adopter household will change their behaviour in an attempt to maximise the benefits (Sommerfeld, Buys and Vine, 2017); also referred to as load shifting and therefore basing their consumption on the electricity prices by selling when the price is high and using when the price is low.

The Norwegian adopter, however, sometimes seem less concerned with the economic benefit and more interested in the technology itself and how it is a good environmental solution as they are often more environmentally aware than the average person (Winther, Westskog and Sæle, 2018; Hansen, Jacobsen and Gram-Hanssen, 2022). There may be a shift in the type adopting lately where the earlier adopters have been more environmentally/technologically interested, while the current ones are more economically minded. Therefore, while environmental performance is important, it may be less important now. In comment sections, environmental performance is barely mentioned, with one exception in a comment section about bureaucracy declining a family from adopting. Commenters wondered if the district municipality really were interested in being environmentally friendly or not. The weights of each driver are, however, set to equal, because it can be hard to comment on which is more important without more interviews or observations. The figure 3.6 below adds an environmental loop as one of the drivers of adoption of solar panels.

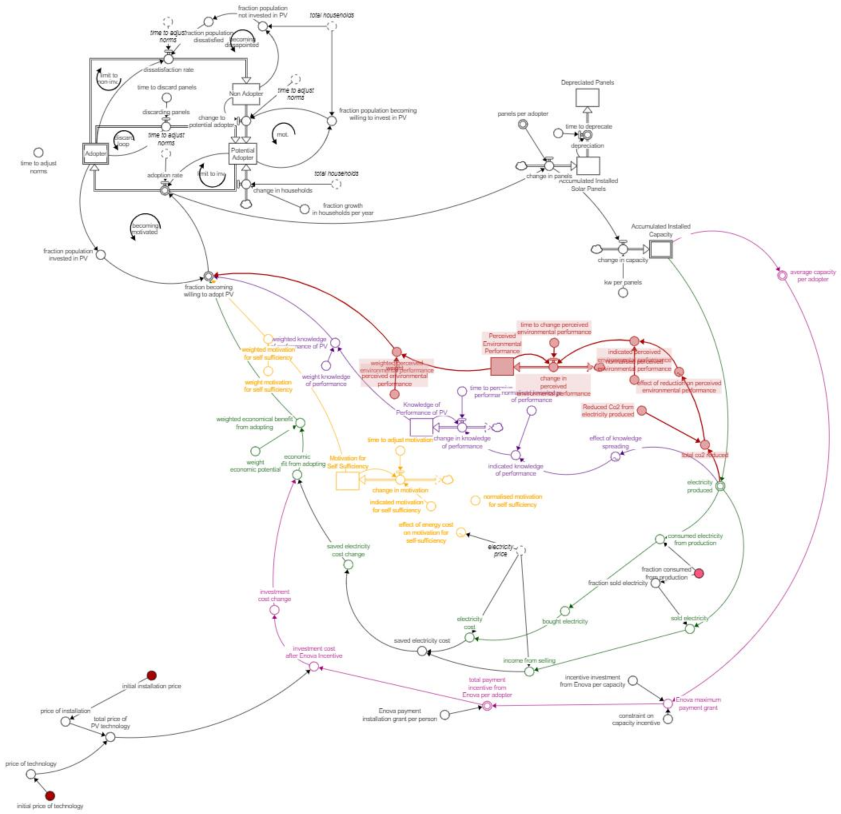

Figure 3.6 – Perceived Environmental Performance.

3.3 Demand-Side: Potential and Non-Adopter

As with the adopter, there are certain drivers for both the potential and the non-adopter. The data from literature is often unclear about the difference between an adopter, potential adopter, and non-adopter, mainly due to often the dichotomous characterization of the population; most studies will focus on potential adopter and adopter vs non-adopter/rejecter and adopters and maybe mentioning the last category with little differentiation made. Some examples of literature where there is a definite difference is Hai (2019) focusing on states of willingness to adopting solar technologies. Using social media, 15 comment sections and one solar panel interest group were examined, mainly from Facebook and to some degree Twitter.

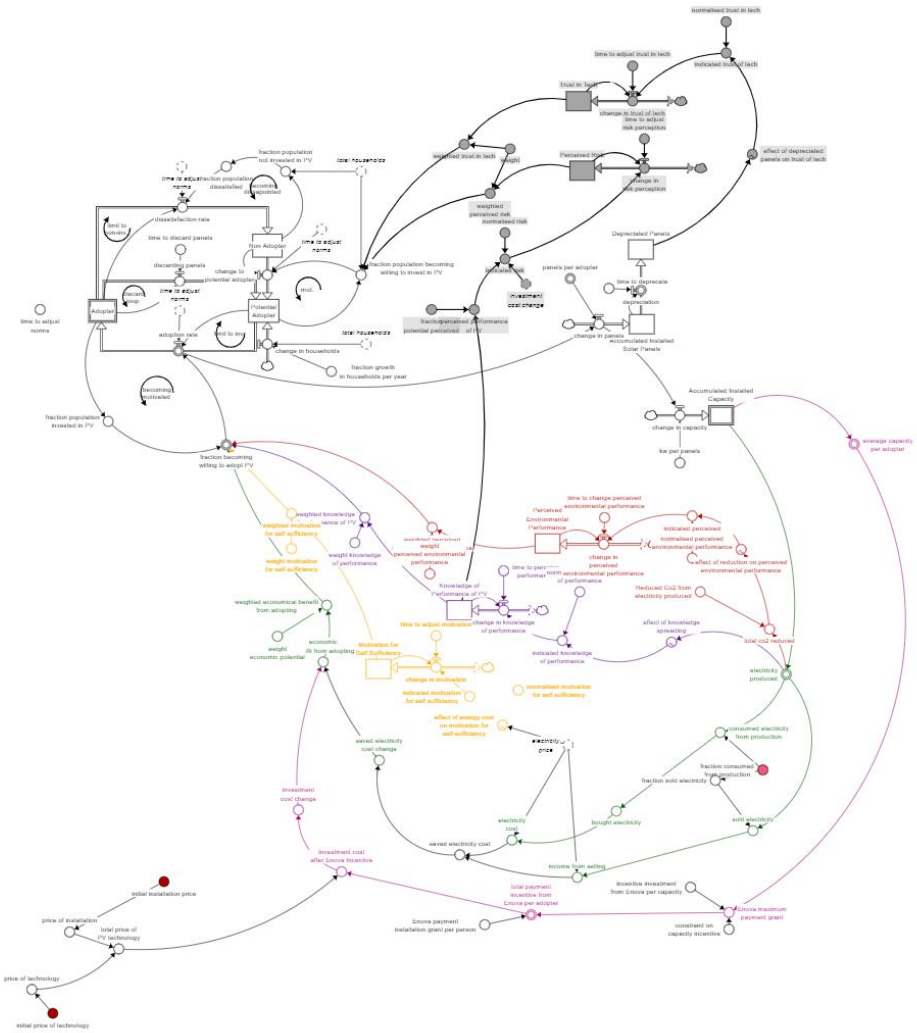

Figure 3.7 – Potential and Non-Adopters.

The overall issue to those who are non-adopters is a lack of knowledge in the technology and the potential of it. The difference in those who actually becomes potential adopters are those who becomes knowledgeable about the potential and shows some interest in the technology. Perhaps with some inner innovativeness that most adopters and seemingly potential adopters possess. The action of becoming a potential adopter is thus becoming knowledgeable about the technology and trusting the technology.

The latter is a problem, as many non-adopters that stay in that stock is very suspicious of the technology, in some cases, even hostile to anything other than hydropower, the known, and several non-adopters also mentions nuclear power, as a better solution in Norway. The definite non-adopter would rank low in innovativeness, compared to the other two groups, and seems less likely to trust the norms of other groups. Some also mention the waste from solar panels. Trust is also mentioned by Chadwick, Russell-Bennett and Biddle (2022) as being important in rejection vs non-rejection of a technology. Lastly, while not explicitly mentioned, many seem to find the investment to be risky because of the price or because they do not know enough of the technology. They will therefore not adopt.

3.4 Supply-side

The supply-side model was mainly built one interview, news, some literature, and with inspiration from basic supply chain models from Sterman's Business Dynamics and models such as the infamous Beer Model. The main purpose for the supply-side is to demonstrate the interaction between the two sides and illustrate how the supply chain can affect the adopters as a limitation even when they wish to adopt. The interview of a supplier in addition to current news resulted in an understanding of the current bottleneck of installation of solar panels. Structure is based on this understanding.

3.4.1 Supplier loops

The suppliers limit the adoption rate by how many panels can be installed. When adopters become motivated to adopt, the demand increases which increases the inflow of orders. If the demand is lower than the suppliers' capacity to install solar panels, then the order of solar panels is immediately installed, only with time delay of how long it takes to install solar panels. This loop is illustrated in figure 3.8 below.

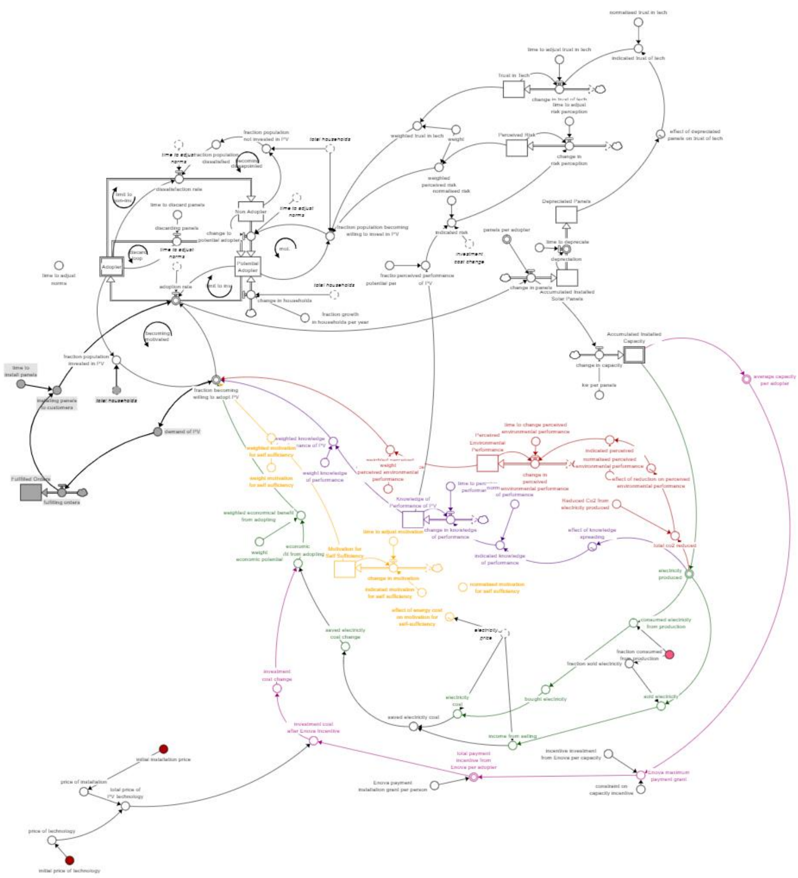

Figure 3.8 – Supplier Loop, lower demand.

In cases where the solar panels cannot be immediately installed, the solar panel suppliers perceive the orders with a delay which is then backlogged into the Backlog Received Orders. The outflow from this stock ensures the stock decreases as more orders are fulfilled and remains at zero when the demand is lower than the capacity.

Further, in order to calculated how many orders can be fulfilled, the received orders flow also decides how much is ordered from the producer of solar panels. Ideally, the supplier will receive just as many solar panels as they are selling. The desired shipment to inventory is the variable that tells how many orders are needed to ensure all customers will acquire the solar panels ordered. However, what is needed and what can be sent are not always the same. This second loop where the demand is higher than the capacity is illustrated in figure 3.9 below.

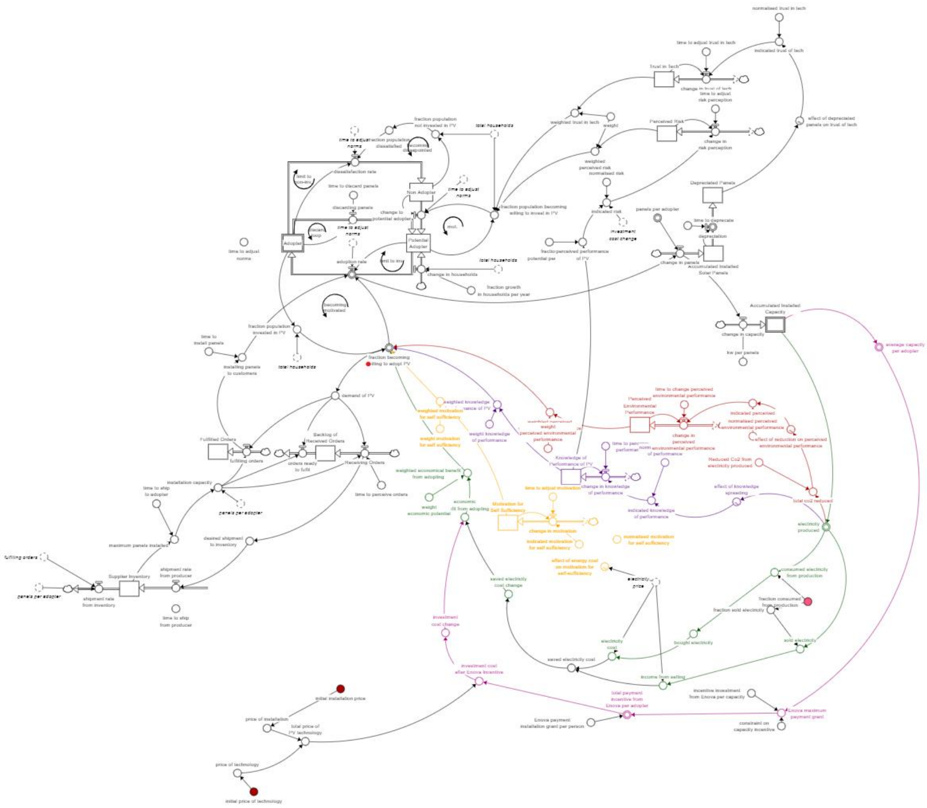

Figure 3.9 – Supplier Loop, higher demand.

3.4.2 Exogenous Supply Chain Interference

The producer may not have enough to fulfil the orders of the supplier. At the receiving orders flow going into the inventory, there is a limitation to the desired shipment to inventory. The producer can only send based on what they have, therefore, this flow only adds to the inventory what is available; this could be less than what is desired. The idea here being that each order comes with a certain number of panels needed. These panels will have to be shipped to the inventory by an external producer abroad. What needs to be to be shipped to the inventory is ideally the same amount as the orders received from customers (if not more).

What is sent from the producer increases the inventory stock, which essentially acts as the sum of all solar panels available in Norway more than one supplier inventory. The outflow from this stock is what is available to be shipped. Here is another constraint introduced which limits the customers: even if there are enough solar panels to be distributed to the adopting customers, there might not be enough installers to install the technology.

What decides if orders are fulfilled is essentially two factors: are there enough panels to supply all customers and are there enough installers to install the panels? By the minimum of these two factors, orders are fulfilled. In other words, if there are not enough installers compared to the potential of solar panels, then it is the installers that decide how much of the orders are fulfilled. If there are not enough panels coming from the inventory, then this is the limitations and decides how many orders are fulfilled. The minimum of these two constitutes the variable maximum panels installed and further the adopter capacity constrained variable. The latter variable is also what decides the flow of customers from the Backlog Received Orders to the Fulfilled Orders.

As orders are fulfilled, they are installed with a time delay based on the time it takes to finish installing a project to an adopter. The installation capacity variable is the constraints which limited the adoption rate mentioned earlier. The exogenous interference of the producers abroad is a structure meant to test how the Norwegian sector is affected different production rates that might happen during supply chain shocks. This could be either lack of access to minerals, competition for solar panels or other occurrences that might disrupt shipment to Norway. In the model, it is a stock of available panels with an inflow (production rate) and outflow (shipment rate from producer). This is a simplification. Recently the supply chain of solar panels has experienced many shocks leading to shortages of panels in several countries, Norway included (OECD, 2022). The exogenous producers can be seen in figure 3.10 below (with installer loops).

3.4.3 Installer loops

Also possibly limiting installation of solar panels are the available installers. The size of the stock is unknown, but according to a news article in 2022, it is too small and limits installations (Korneliussen, 2022). Further, the article states that vocational training in upper secondary schools should contain installation of panels which it does not currently do. Despite of this, people attending the electrician or similar vocational tracks in upper secondary schools may choose to do a two-year apprenticeship in solar installation as a part of the schooling[2]. One of the interviewees in the news article, a solar innovator and installer, desires specialization in solar panels as a part of the electrician track. As installers is a limiting factor, the stock has been set to a low value with an assumption that it will grow based on the demand. In the figure (3.10) below, this is illustrated by a graphical effect variable where the growth in demand linearly affects the growth rate.

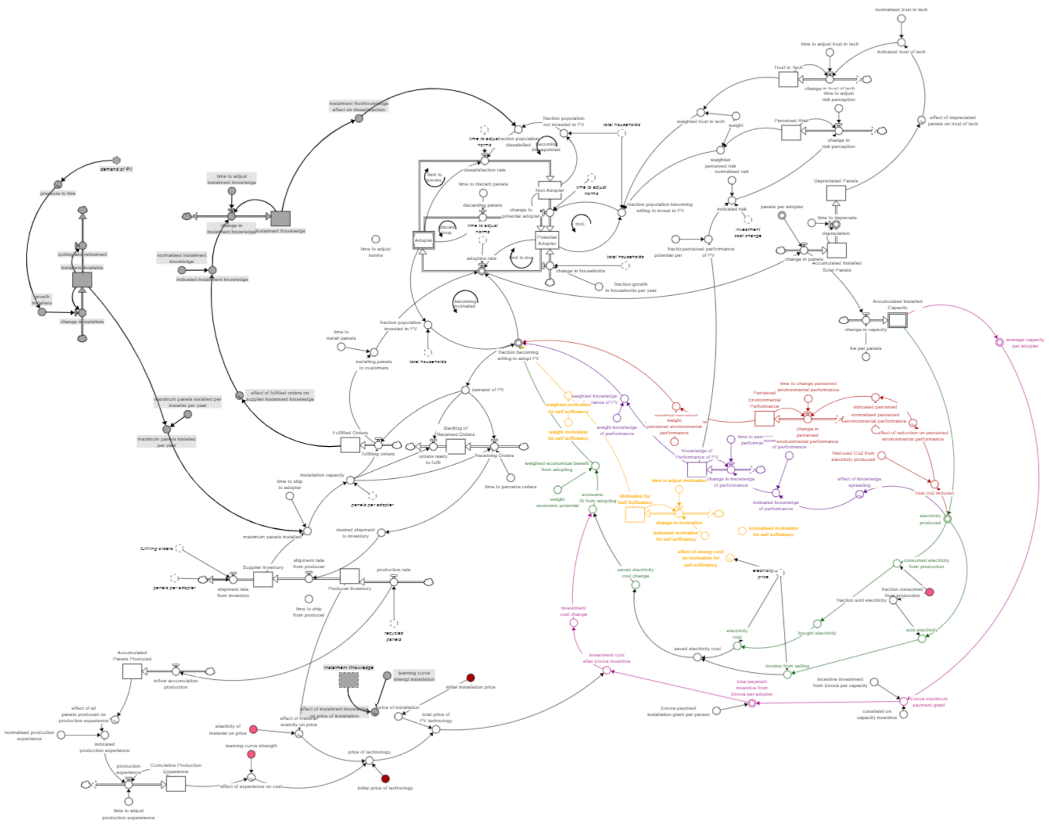

Figure 3.10 – Exogenous Producer and Installer loops.

In addition to the availability of installers loop, there is a loop of knowledge that affect satisfaction in the use of panels. The knowledge of the installers of the panels are reported to be causally linked to the satisfaction of the customers (Garlet *et al.*, 2019; Aboagye *et al.*, 2022). The study by Aboagye who focused on the effect of the design, installation, operation, and maintenance on the performance of the solar panel, found that adopters will chose to not re-invest if they are not satisfied with the solar panels. Further, they comment that it is crucial the adopter is educated on effective use of the technology, to avoid malfunction and the subsequent dissatisfaction. Garlet et al. (2019), stated similar findings that improper knowledge by the user

[2] Vocational tracks in upper secondary schools are typically two or three years of (mostly) practical in-school schooling. For electrician studies, it is one year of general electric studies and two years specialized studies proceeded by a two-year apprenticeship concluded with a practical exam showing the pupil's skills (Vilbli.no, no date).

and the installer could lead to a negative perception of the technology. The fraction dissatisfaction is therefore dependent the knowledge of both the installers and the user. Correct installation coupled with the ability of the adopter was also mentioned as important factors for maintaining the solar panels and avoiding malfunction.

3.5 Model Boundary

The model has several boundaries set to simplify the system. Firstly, there is a geographical boundary focusing on the diffusion of solar panels in Norway. The structure belonging to producers abroad are more for the sake of testing different scenarios for how diffusion is affected by a potential constraint from the supply line. Additionally, the focus is on the prosumer, excluding all solar panels owners who are not connected to the power grid. The electricity price is fed into the model exogenously.

3.6 Main Assumptions

There are several assumptions made in the model. Firstly, I assume all solar panels adopted are of the same type of technology, meaning I do not differentiate between the different types of solar panels on the market.

Secondly, for graphical functions, it is difficult to know the shape of the effect from one variable to the next. Additionally, as there are several information/knowledge effects on other variable, I have had to make assumption in what variable makes this effect. For example, knowledge about the potential come from the Adopter stock, basically saying that the more adopters there are it creates more available knowledge about the potential of solar panels. The same goes for the effect of production on price, a simplification of economies of scales, where the learning from production is what decreases the price.

Chapter 4 MODEL VALIDATION

The model has been developed per literature and interviews conducted. While data on the demand-side of the diffusion process where copious, there are some uncertainties of variables. In some cases, there were either a range of values from literature or no found data. The uncertain or unknown parameters were calibrated to historical data.

I have taken multiple steps to build confidence in the model for the purpose of validating the model structure and behaviour. Validation tests are varied in system dynamics and generally separated in structural tests and behavioural tests. Firstly, validation of model structure means having a structure that does not contradict reality, which includes both the causal effects across the model and the parameters; parameters also needs to be real and within logical values (Forrester and Senge, 1979). Unknown parameters are used to calibrate the model (Oliva, 2003) and by this compare the existing historical data to the model output.

The tests ranges from calibration, extreme testing, structural tests, unit dimension test, parameter test, integration error test, sensitivity analysis, behaviour reproduction test, and behaviour anomaly test, per validation procedures of Sterman's Business Dynamics (2000, pg. 859-861). Tests like behaviour reproduction test, dimensional unit correctness test, structural test, and parameter test have been conducted continuously as the model has progressed to ensure the structure is replicating reality as close as possible at all points of the model development.

This chapter presents the summary of all tests conducted to build confidence in my model.

4.1 Calibration

The model has been calibrated after conventions found in literature (Homer, 1983; Oliva, 2003). The purpose of calibration has been to validate the model. At each point in the model building, it was calibrated to fit the historical data.

4.2 Unit Dimension test

The units of the model are dimensionally correct without fuzzy variables.

4.3 Structural Test

This test is related to the causal structures elicited from literature and interviews. To validate the structure, I have used triangulation of the data from the two collection methods to ascertain the structure is sensible. The aim, in the end, is a model structure that closest mirror reality. As far as it is possible, this test has been passed within the limits of the researcher's own interpretation of the available literature and interviews.

4.4 Behaviour Replication Test

The historical data in this model relates to data on the installed capacity from prosumer solar panels and number of prosumers reported. As is, the model replicates historical data adequately, something achieved from finding parameter data and calibrating the model.

4.5 Extreme Conditions Test

The model is tested using extreme values. The purpose is to ensure the model withholds its logic even with extreme values. E.g., using 0 for capacity per panel means capacity stops increasing and start decreasing due to depreciation of the panels. On the other hand, using a value such as 10000 for the capacity per panel would increase the installed capacity, as it should. The model passed this test.

4.6 Parameter Test

The purpose with the parameter tests is to ensure that all parameters are consistent with the data collected and real world. All parameters, whether calibrated, estimated or found in literature, need to be realistic and within a range of numbers that can be found in reality. This stands true for the model.

4.7 Integration Error Test

The model uses Euler integration method but was additionally tested in the Ranga-Kutta 4 integration method. Changing the integration methods, did not result in an unreasonable change in behaviour, beyond minimal differences in a few numerical values. E.g., in the Adoption Stock, the difference is less than 1% at the end of the timeframe when using Euler's vs. Ranga-Kutta integration.

4.8 Sensitivity Testing

The sensitivity test is useful for building confidence in uncertain variables. By testing a range of values on uncertain parameters on the model, it gives insight into the effect on other key variables of the system. Additionally, sensitivity testing gives insights into sensitive area of the model, which could act as leverage points for policies (Ford, 2003). However, the main purpose in this model was to see the effect of uncertainties on the model output. I used Sobol Sequence

Sampling and a uniform distribution for all tests with varying Starting and Ending values depending on the parameters and my own judgement of logical ranges of values.

The main variable to examine the effect on was adopters, however, *fraction becoming willing to adopt PV* was checked in instances where the demand of solar panels was higher than the capacity. In these cases, there would be no effect on adopters, but there possibly could have been an effect, had there been a higher capacity in the solar market. Therefore, when there are constraints to the adoption rate, I would use *fraction becoming willing to adopt PV* as a proxy to see if there are any potential to policies.

A summary of the sensitivity test is presented below with more sensitivity analysis in the appendix.

4.8.1 Summary of Sensitivity Tests

Parameter and Type of Sensitivity Test	Incentive investment from Enova per capacity Uniform, Sobol, 500-10 000

The *adopter* is somewhat sensitive to the *incentive investment from Enova per capacity* at some point in the simulation. It could aid adoption around the time where potential adopters start thinking about adoption. It might be more sensitive without the constraint from the suppliers as they all approach the same number of adopters. Concluding from that, without capacity issues at the supply-side, it might be impactful policies.

Doing the sensitivity test without the constraining variable in the adoption rate inflow, results in the behaviour in the figure below (figure 4.1) showing a quicker adoption. Adoption is therefore sensitive to the incentive by Enova.

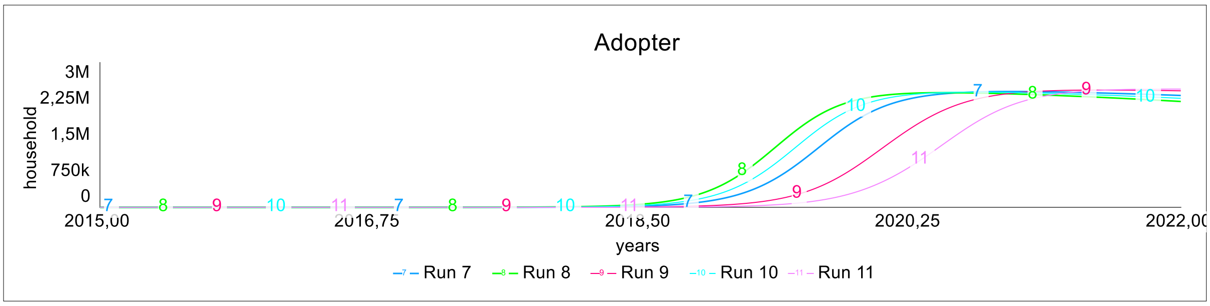

Figure 4.1 – Sensitivity test without supplier capacity limitation to growth.

Parameter and Type of Sensitivity Test	Maximum panels per installer per year Manually, 10-600.

The maximum panels installed is sensitive to how many panels can be installed by one installer per year. There is, however, a constraint as can be seen met in all runs the last two (500 and 600) illustrated in figure 4.2 below. The flat development of *maximum panels installed* is when installers cannot install enough panels comparative to how many panels are available; the installer's capacity to install is, in other words, too low.

Depending on the initial value of the *supplier inventory*, are there differences in how much capacity of the panels installed. This interaction between installers and their capacity to install and the available panels in the inventory is important on the supplier-side and is significant in increasing the capacity to supply customers. Consequently, this could possibly be a policy to maximize the capacity of the supply-side.

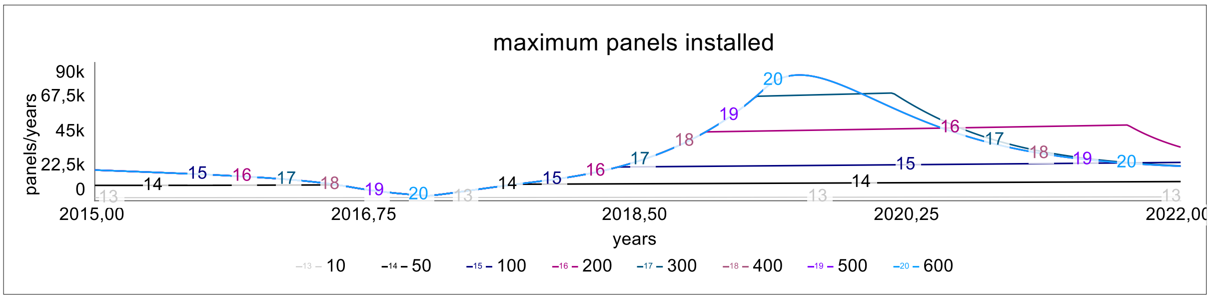

Figure 4.2 Maximum panels per installer per year on maximum panels installed.

Parameter and Type of Sensitivity Test	Initial Installers Available Uniform, Sobol, 0-1000 Note: maximum panels installed per installer per year decreased to 100 panels per installer per year to show sensitivity.

As seen in figure 4.3, there is a possibility of increased panels installed per year. Having a ready workforce of installers can be a beneficial policy. It all depends on the balance between solar panels available in the inventory and how many installer there are.

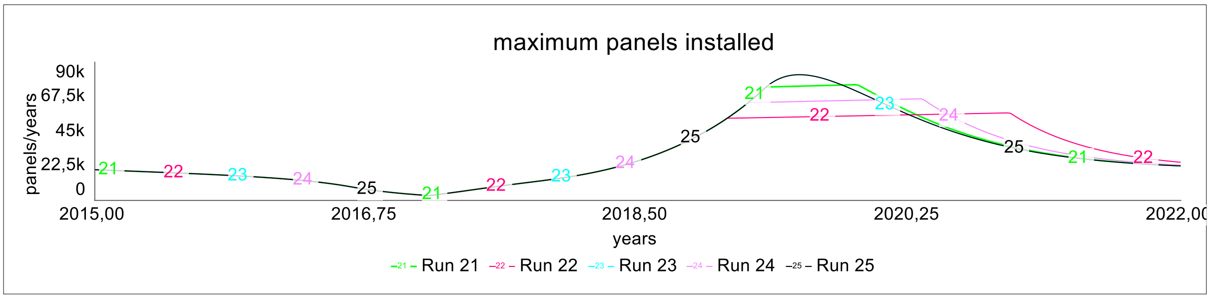

Figure 4.3 – Sensitivity effect of initial installers.

Parameter and Type of Sensitivity Test	Initial Supplier Inventory Uniform, Sobol, 0-200 000

The *maximum panels installed* is sensitive to the initial number of solar panels in the inventory. Available solar panels is therefore important for the capacity of the suppliers. A higher number of solar panels available means a higher capacity to install (until there are not enough installers as seen in figure 4.4 below). Adopters will grow quickly based on the balance between installers and the solar panels inventory. Addressing this might aid expanding the capacity and will be tested in the policy discussion.

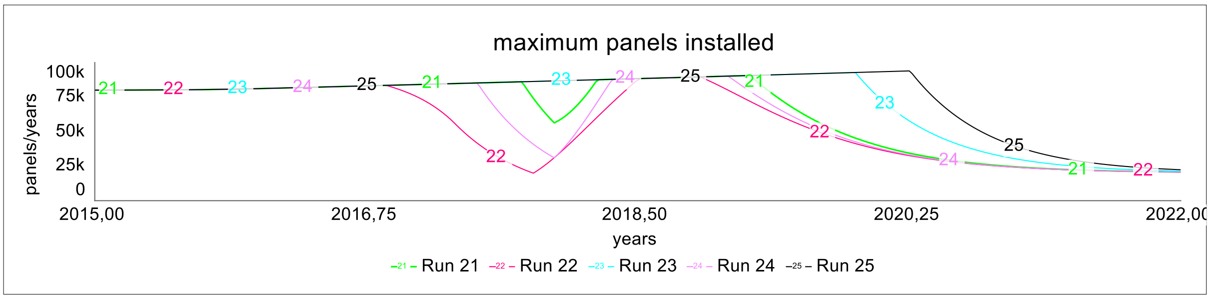

Figure 4.4 – initial supplier inventory effect on maximum panels installed.

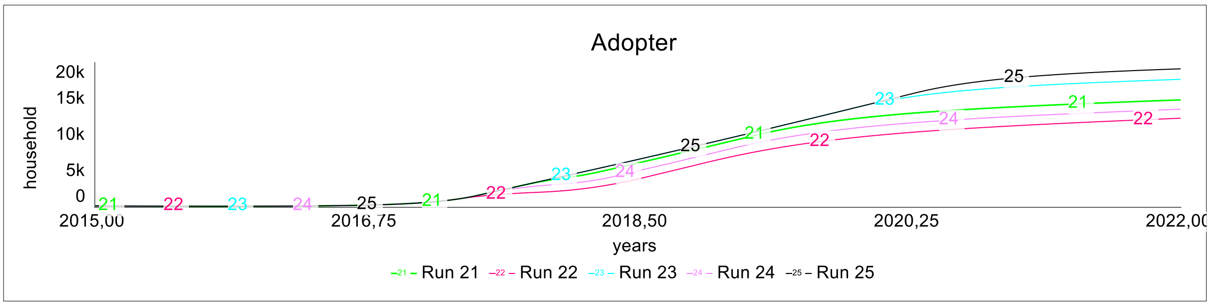

Figure 4.5 – initial supplier effect on adopter.

Chapter 5 SIMULATION RESULTS

The purpose of the thesis is to understand the drivers of diffusion of solar panels in Norway and its interaction with the supply-side. The model consists of the different drivers and how the benefits are communicated throughout society and the relation to the suppliers of the solar panels.

This chapter presents the model output for diffusion of solar panels (section 5.1) and its interaction with suppliers of the solar panels and consists of a Business as Usual (BAU) scenario and an ideal production rate scenario. A thorough explanation of the scenarios is provided in section 5.2 and 5.3. Lastly, section 5.4 summarizes the chapter.

The figure below illustrates the model output and real data from 2015 to 2022 showing the replication of behaviour for adopter.

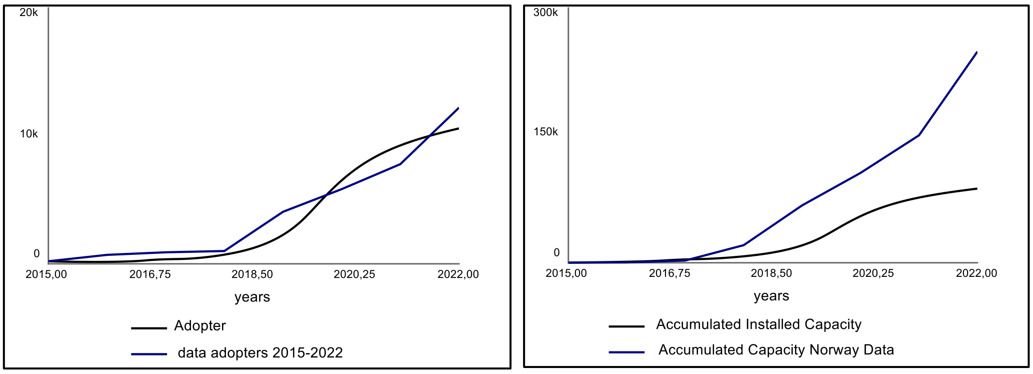

Figure 5.1 – Adopters and Capacity historical data.

Although the second behaviour model (capacity) may display an imprecise development, it is not necessarily incorrect. While a speculation, it might be because 95% of all prosumers in Norway produces 50% of all electricity and the 5% of prosumers produces the rest of 50% (NVE, 2022c). Additionally, the earlier prosumers tended to buy more panels, so when NVE states *most* prosumers have around 10 kW systems of panels installed, they do not account for the average. The average capacity is therefore probably higher than the value found in literature. Nonetheless, the behaviour increases as more people adopt solar panels over time.

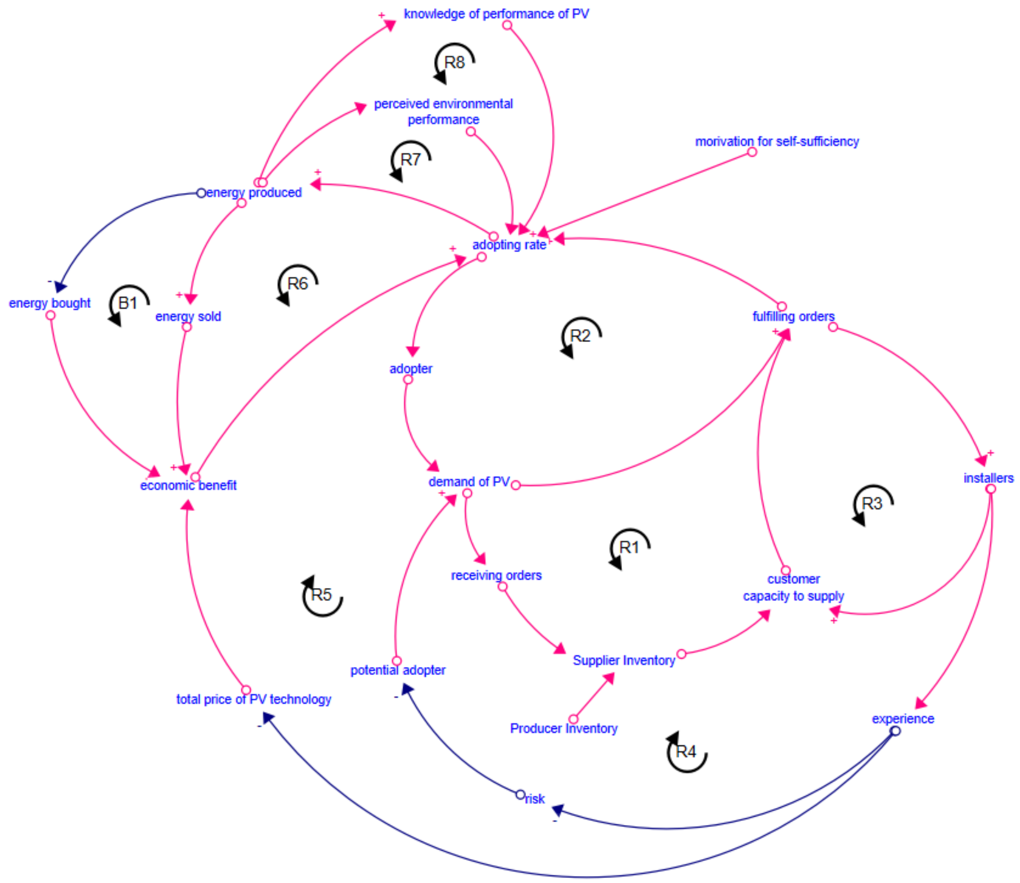

Figure 5.2 – Significant loops of the interaction between supply and demand.

Figure 5.2 illustrates the most important loops driving the adoption of solar panels process. It demonstrates that the drivers are mainly a series of reinforcing loops that increases the adopters of solar panels. The intersection between the three loops B1, R5, and R6 calculates the economic benefit of adopting solar panels. More energy produced by the adopters means more energy sold (R6) increases the economic benefit because more energy is sold, and they receive more income. Additionally, more energy produced mean the adopters have to buy less energy and save money they otherwise would have spent on electricity (B1). The economic benefit therefore increases when they decrease the energy bought. The interaction between loop B1 and R5 is therefore important for the increasing economic benefit. Loop R6 also interacts here, coming from the supply-side, basically saying how experience from the installers decreases the price of the investment. This price is also decreased by an exogenous factor from the producer of the panels being essentially an excluded learning curve loop, coming from all experience of production of solar panels abroad. Further, knowledge is an important factor in the demand-side loops, as well. Loop R3 illustrate how the diffusion of the knowledge of the performance of solar panels is important. With more adopters, it spreads the idea of how it works in Norway. Additionally, despite an almost perfectly decarbonised energy system, there are a reported environmental benefit of PV panels loop (R2), which has been deemed very important for the environmentally aware adopter in Norway.

Lastly, with a higher demand of solar panels, there are constraints to how many can become adopter. Three loops interact at the supply-side depending on two factors: how many installers are available to install in the area and how many panels are available. Therefore, there are limits to how many adopters every year depending on the availability of these which thus constraints the process of adoption.

5.1 Demand-Side Simulation

Starting in 2015, there are 2015 adopters of solar panels in Norway. By the end of 2022, this has increased to around 10 000 adopters. As previously mentioned, there are four drivers of adoption, in addition to the word-of-mouth effect.

The WOM-effect is important in the setting. In the beginning, when there are only 200 adopters of the whole population, there are less people available for the diffusion of the technology – this is calculated at the *fraction population invested in PV* variable which is essentially the density of the adopter population and the whole population and starts at 0.0001. As more households become adopters, this fraction increases towards 1. Thus, as time passes, the WOM-effect increases due to the increase in adopters and therefore also increases the drivers by the same amount as the calculated density. The extended loop of the supplier loop (R2) contains the WOM-effect and is the strongest reinforcing loop, contributing to +24.26% of all behaviour. The effect is therefore important in how diffusion of solar panels occurs.

The overall development of the drivers changes over time and follows an upwards trend. With the economic benefit (R6, B1), adopters are earning an income from the production of solar energy, and consequently reducing their electricity bill, a great benefit for an economic adopter. However, the cost of investment (R5) moderates the economic benefits. In the beginning, the cost is high, but fortunately, with more experience to both the installer and producer, the investment cost deceases allowing the *economic benefit from adopting* variable to grow in strength over time. Of all the drivers in Norway, it is the economic benefit from adopting that contributes most to the increase of adopters by saving on the electricity bill. Figure 5.3 below illustrates the development.

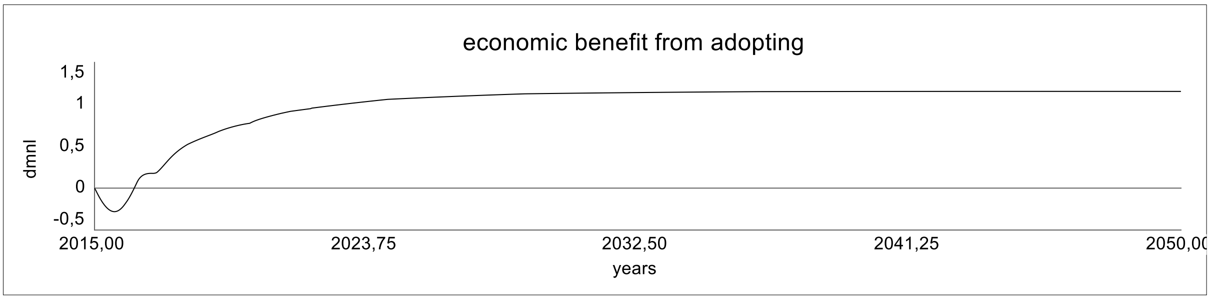

Figure 5.3 – Development of economic benefits from adopting.

Established in chapter 3, is that knowledge matters for adoption of solar panels. This knowledge is conceptualized to come from the *energy produced* variable. As more energy is produced by the increase of adopters, the knowledge of the performance of panels are diffused in society. The stock of the knowledge starts at 0.5, assuming some knowledge of the performance is already there from non-prosumer use of solar panels. It increases as it tries to approach 1 with a decrease in 2020 when the electricity prices decreased significantly in Norway.

Further, the motivation for self-sufficiency starts at 0, an assumption based on the reasoning that supplying energy in the household as a prosumer is new, and motivation adjust over time. This variable is not included in a loop but calculates from an exogenous source for electricity prices. The development knowledge of performance and the motivation for self-sufficiency can be seen in figure 5.4 and 5.5 below.

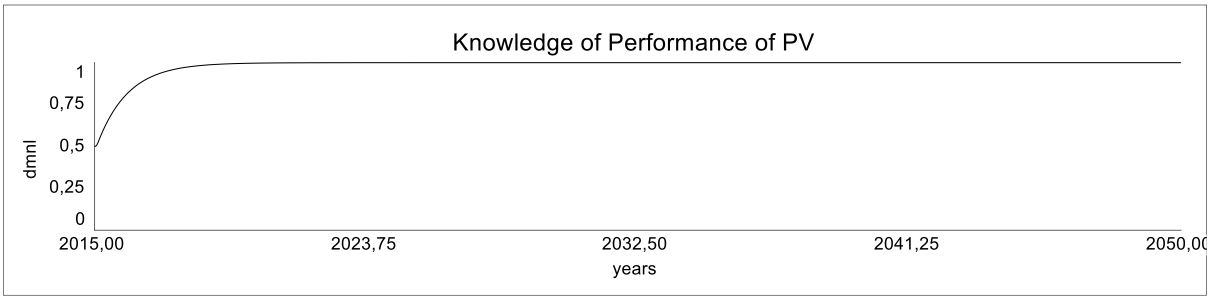

Figure 5.4 – Development of knowledge of performance.

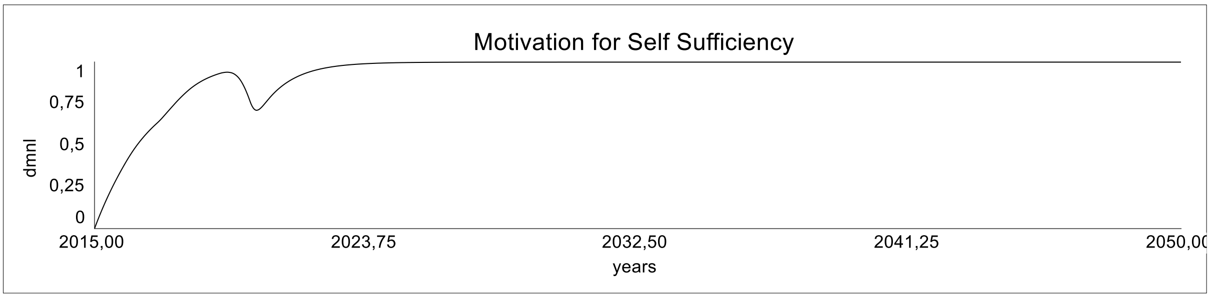

Figure 5.5 – Development of motivation for self-sufficiency.

The motivation increases quickly with the growing electricity prices between 2015 and 2018 but drops in 2020 when the electricity prices decrease. This stabilization stops as electricity prices starts to increase at the end of 2021. Should the electricity prices reduce after 2022, then this driver is extremely sensitive to this and the motivation for self-sufficiency consequently decreases.

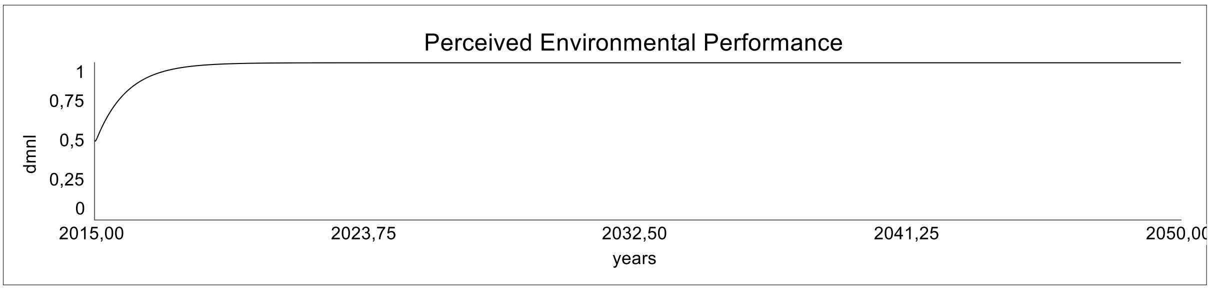

Figure 5.6 – Development of perceived environmental benefits.

Lastly, as many adopters of solar panels are environmentally interested people, is the driver *perceived environmental benefits (*figure 5.6 above*)*. Based on how much Co2 is saved per adoption, potential adopters will perceive the benefit. Starting at 0.5, it develops slowly in the first few years, mainly because the adopters and thus energy produced is low but speeds up with more adopters.

In terms of the strength of the loops of the drivers, none contribute significantly to the change in behaviour of the system. The WOM-effect incorporated in R3 is the strongest reinforcing loop affecting the adopter stock. This loop is not on the demand-side of the model. This might be strange considering the drivers is why adopters adopt solar panels. Nevertheless, it is not incorrect. Due to limitations on the supply-side, most behaviour is driven by the capacity to supply solar panels.

5.2 Supply-Side Simulations

As mentioned in the previous section, the most dominant loops are not the drivers of solar panel adoption, but rather the loops on the supply-side because of the of the capacity of the suppliers to supply solar panels to the customers. There are two loops of significance on the supply-side and then an exogenous producer driving the capacity in addition to installers. In 2015, the demand of solar panels starts at 134 households which increases, but with a higher capacity to supply.

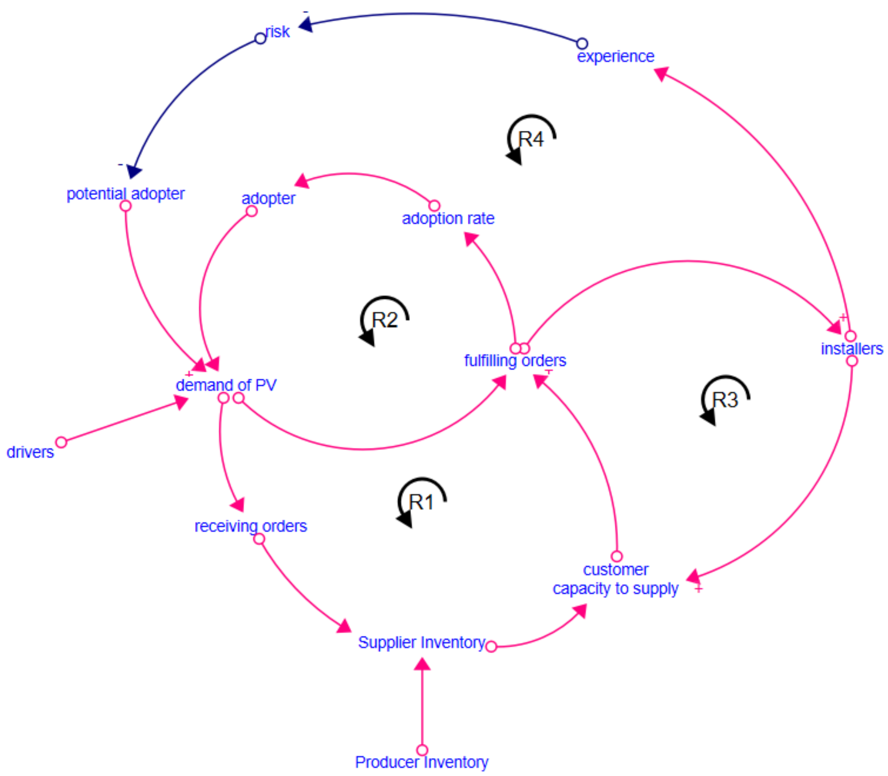

Figure 5.7 – Significant Loops Supply-Side.

One of the prominent loops driving the increase of adopters is the loop R2 (figure 5.7 above). As the demand is lower than the capacity of the suppliers, all customers receive an offer of solar panels with an assumed no delay. The *backlog of received orders* remains the same because the inflow is zero. This will change when the *demand of PV* grows larger than the *installation capacity*. When this occurs, there is also a shift in loop dominance. While the suppliers could until then supply the demand without waiting times, now the customers accumulate in the *backlog of received orders*.

From this instance, the primary driving force of adoption changes to loop R1. Because the supplier cannot immediately supply the solar panels desired by the demand, the customers must wait to receive their offer of solar panels. To increase the capacity, the supplier requires more panels from the producer. At this period of time the producer inventory is large enough to ship the desired number of panels based on the demand. The outflow of the *producer inventory* hence increases the supplier inventory. The inventory decides *the installation capacity* in combination with the available installers and by this the orders are fulfilled. This loop increases the adopter stock until the *producer inventory* are at such low levels that it cannot provide the value of the *desired shipment from producer*. At this point, it is neither loop R1 nor R2 increasing the behaviour but depends on the exogenous producer.

The interaction between supplier and producer at *the shipment rate from producer* flow, is one of the limitations of the supplier-side. Indeed, if the producer cannot supply what is needed, then the supplier will only receive the minimum of what is ordered. In the model, this is conceptualized by a minimum function in the equation, which determines the minimum of the *desired shipment to inventory* or the capacity of the producer to ship. At the time when the producer abroad cannot ship the desired amount, the dominance shifts. From this point, the increase of adopters is driven by an exogenous source rather by the loops R1 and R2.

Furthermore, as the suppliers are not receiving what they want from the producer, there is also a decrease in the *supplier inventory*. Because the supplier inventory decreases, the capacity to supply solar panels also decreases. The variable *maximum panels installed* reduces which means less customers can receive there offers. By 2022, the *installation capacity* has decreased significantly following the behaviour of the inventory.

5.2.1 Other Interactions of Suppliers

The supplier also interacts with the potential adopters through installation price and the dissatisfaction rate. As mentioned in chapter 3, there is a connection between knowledge of the installer and the installation price. As the installers acquire more knowledge, their prices decrease. With a decrease in price of solar panels, it becomes more attractive to invest in solar panels. Over time, we see the *economic benefit from adopting* increase. This loop will also increase potential adopters, as when the price decreases, the technology is also perceived as less risky by non-adopters and more might become potential adopters. With more potential adopters, the demand increases which affects order rate.

Secondly, also due to installation knowledge affects the *dissatisfaction rate*. While not one of the most important loops, the knowledge loop ensures the flow from adopters to non-adopters remain low and thus the outflow from adopters because of dissatisfaction with the panels does not affect the adopter flow to much. In fact, it approaches zero by 2022, being only about one dissatisfied adopter every few years in the end. The loop is therefore not significant to the behaviour of the system.

5.3 Ideal Production Rate Scenario

In this situation the production rate is equal to the *desired shipment to inventory* variable. With some delay, it increases the producer inventory. The effect on the adopter population is a much higher diffusion of solar panels than in the situation where there is a much lower production rate than what is desired. Hence, there are no limitation from the inventory. The adoption rate now depends on the installers and their capacity to install solar panels. As seen in the figures 5.8 and 5.9 below, the new production rate affects the capacity of the supplier.

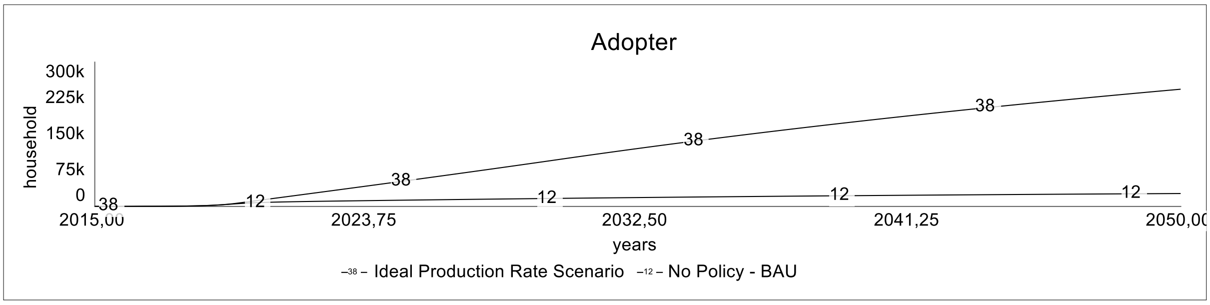

Figure 5.8 – Ideal production rate effect on adopter.

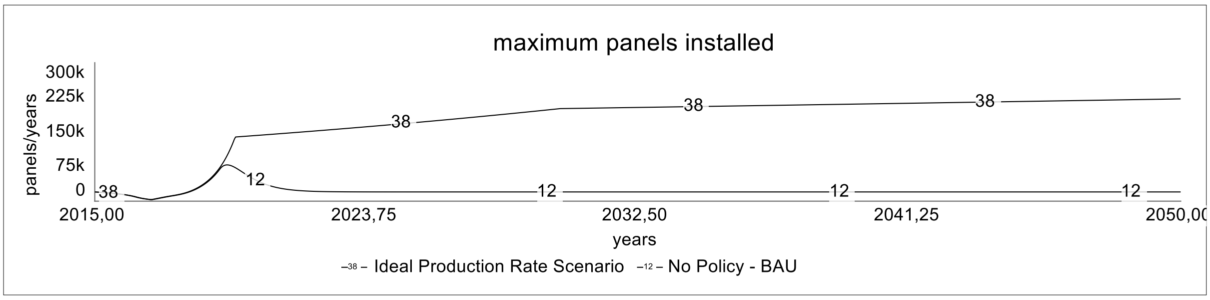

Figure 5.9 – Ideal production rate effect on capacity.

Figure 5.9 shows similar behaviour in the ideal scenarios as when there is a constraint; the flattened, slightly increasing shape of the curve increases slowly with the slow increase of hiring based on the pressure from demand. There are still not enough installers to install the available solar panels. Therefore, the ideal scenario for production is only ideal if there are enough installers.

Interestingly, the second most dominant loop in this case with a loop score of +13.96%, is the loop decreasing the price of the technology and hence also the price of the investment; this will again affect the economic benefit loop by making investing more attractive. With scarcity of material, the price increases, but as they are producing more than enough solar panels, the price decreases significantly making the investment beneficial. As the capacity of the supplier also is much higher (even when limited by installers), the loops of the drivers of adoption are also much stronger than in the business-as-usual scenario. This illustrates the effect of scarcity of materials on the price of the technology and the likelihood of adoption.

5.4 Summary of Simulation

The simulation output indicates that adoption of solar panels in highly influenced by the supply-side, especially by a sufficient availability of solar panels and skilled installers. The drivers of solar panel adoption are not the strongest loops driving the increase of adopters. Instead, the loops concerning the suppliers of solar panels is what drives the behaviour when the adoption rate is constrained. However, with an optimal production rate, as explored in the ideal production rate scenario, adoption rates will increase drastically, only somewhat constrained by too few installers which limits the growth. Nevertheless, the adoption rate and the resultant adopters are much higher in contrast to the BAU scenario.

Chapter 6 POLICY DISCUSSION

The sensitivity test revealed that there is not much too potential on the demand-side. While the economic benefit from adopting is sensitive to changes in an already implemented policy from Enova, it does not affect the adoption rate much except for the beginning stages of the simulation, even without the constraint of the supply-side. The supply-side, however, has several sensitive areas where policies can be implemented which will aid adoption of solar panels.

Two policy options will be explored with the goal to facilitate adoption. Firstly, a policy concerning the availability of installers to increase the capacity to install solar panels. Secondly, a policy option with circular economy in mind by fixing and re-selling or recycling solar panels. The first policy option is a policy that concerns with the installers of solar panels. As it is, there are enough because of material delays, however, should the delays clear then installers are needed. The policy involves educating and hiring more installers to install solar panels.

The second policy option proposes an inventory scheme for solar panels. This means recycling panels that does not work, while re-using panels that might work. While the fraction recycled or fraction reused is unknown, I will test several options and estimate the effectiveness and at what point it potentially be effective. This policy would most likely come with several implementation challenges which will be discussed in section 6.4. Lastly, the policies will be combined to examine the possibility of increased adoption of solar panels.

The chapter is structured as such: in section 6.1, I will discuss and present the first policy option of increasing the installers to aid adoption of solar panels. Section 6.2 is about the second policy option on reusing and recycling, while section 6.3 is a combined policy. Lastly, in section 6.4, I reflect on implementation of the policies and potential issues. Section 6.5 summarizes the chapter.

6.1 Hiring Policy

From the sensitivity testing, it was established that available installers and their ability to install solar panels affects the capacity to supply customers. Too few installers might constrain the adoption rate. Based on this knowledge, one possible policy could be to hire more installers and/or focus on the productivity of the installers by increasing the panels installed per installer per year. In the previous chapter the initial available installers were 300 in 2015 and grows depending on the demand and by the end of 2022, there were 261 installers – a modest growth. This growth of installers is illustrated in the figure 6.1 below.

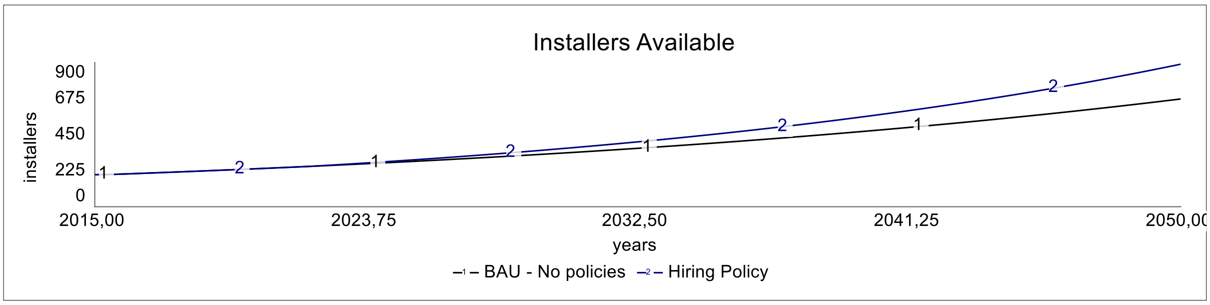

Figure 6.1 – growth of installers between 2015 and end of 2050.

Parameter	**Value**
No Policy Fraction growth	0.03 * effect of demand (dmnl)
Hiring Policy Fraction growth	0.07 (dmnl)

Table 6.1 – Hiring Policy Parameters.

Before 2022, the policy would be to hire installers at a rate of 0.06 and then increasing the hiring rate to a fraction of 0.07. Table 6.1 above details the policy parameters of the hiring policy. With this, there is an increase of new installers and increases to about 889 installers available in Norway by 2050. The difference between the policy on and off is about 217 installers in 2050 (figure 6.1 above). There would be growth in both situations, but with a higher increase in the case of the policy turned on.

This increase is rather modest even when it increases by four over the time period. Nevertheless, it is still the inventory that decides who many panels are installed. In other words, there are enough installers for the solar panels with this growth, but there are not enough solar panels to install. This results in an ineffective policy on its own. This ineffectiveness of the hiring policy can be viewed in figure 6.2 and 6.3 below which shows the non-existent effect on *maximum panels installed* and the resultant *adopters*.

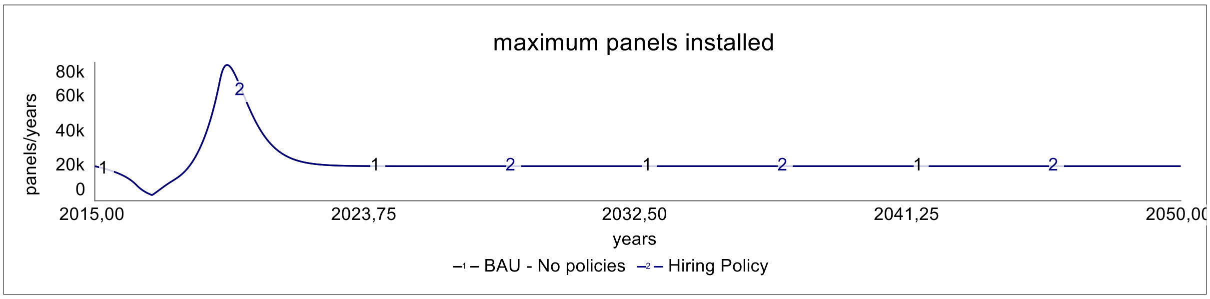

Figure 6.2 – Hiring policy effect on maximum panels installed.

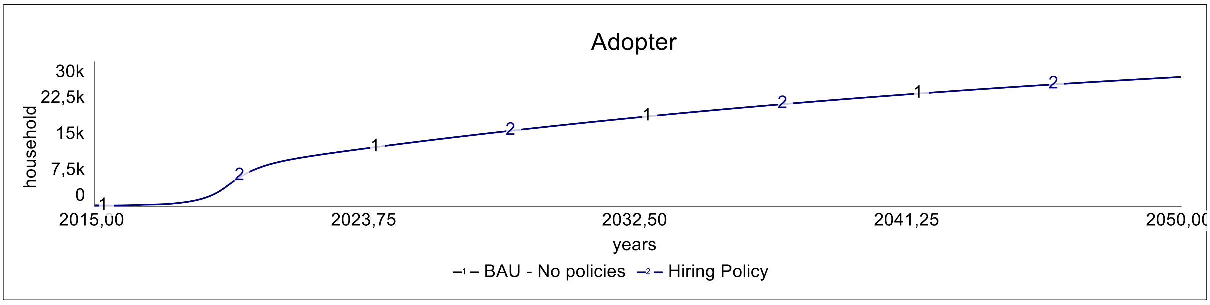

Figure 6.3 – Hiring policy effect on adopters.

A hiring policy with continued problems with the supply of solar panels would be a non-effective policy. On its own, this policy would be expensive, yet with no impact on the increase of adopters. Therefore, there needs to be an additional policy that also addresses this issue to increase the adoption of solar panels. The reason for this happening is, as mentioned, the lack of supplier inventory. In a case where there are enough solar panels, it is R5 driving the supply-side, because suppliers can only provide solar panels based on the minimum of installers or solar panels. In this policy, however, there is not enough solar panels and hence, the dominant loop continues to be R1 (figure 6.4 below).

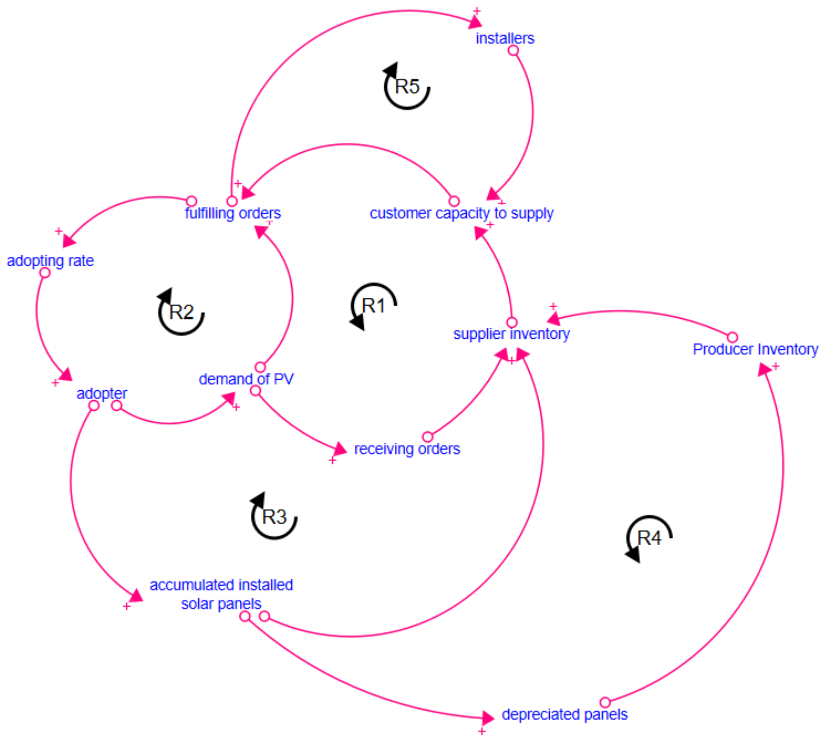

Figure 6.4 – Policy Loops.

6.2 Inventory Policies

The previous section established that a hiring policy would not be impactful in this situation even though the sensitivity analysis found the *adopter* population to be sensitive to changes in the parameters *hiring fraction* and *maximum panels installed per installer per year*. Hence, there is a need to address the supply of solar panels. This inventory policies addresses this and will be done by introducing a recycling and reusing policy scheme. The goal is thus to find if this scheme is enough to increase the inventory, so that the capacity of the suppliers increases.

In the recycling policy, discarded solar panels are shipped to a recycling facility and further to the supplier inventory. Reused panels, on the other hand, is directly sent to the supplier inventory with a delay of half a year. This gives the supplier the responsibility of re-distributing panels. Table 6.2 below details the fraction recycling panels and the fraction reusing.

Parameter	**Value**
Fraction recycling	0,1 dmnl/year
Fraction reusing	0,04 dmnl/year

Table 6.2 – Parameters Inventory policy.

Considering how the supplier inventory was constraining the installers in hiring policy option, the second policy addressing this has been impactful. By introducing both reuse and recycling, the inventory issues has improved. Figures 6.5 and 6.6 illustrate how the inventory for the supplier and for the producer of panels increases over time.

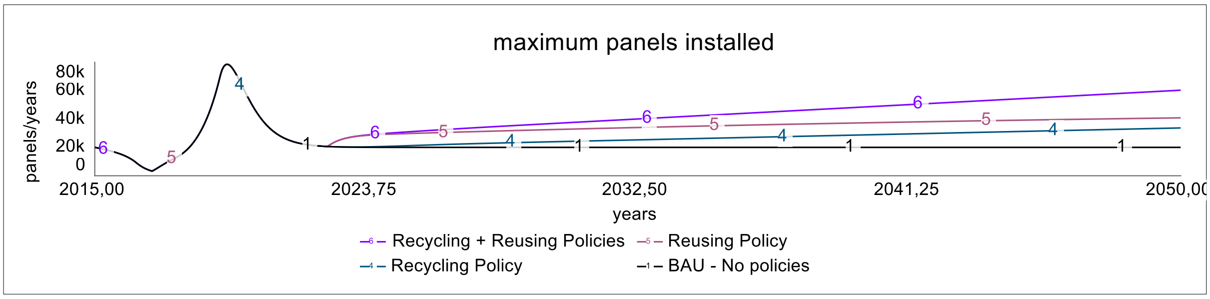

Figure 6.5 – Comparative effect on Supplier Inventory.

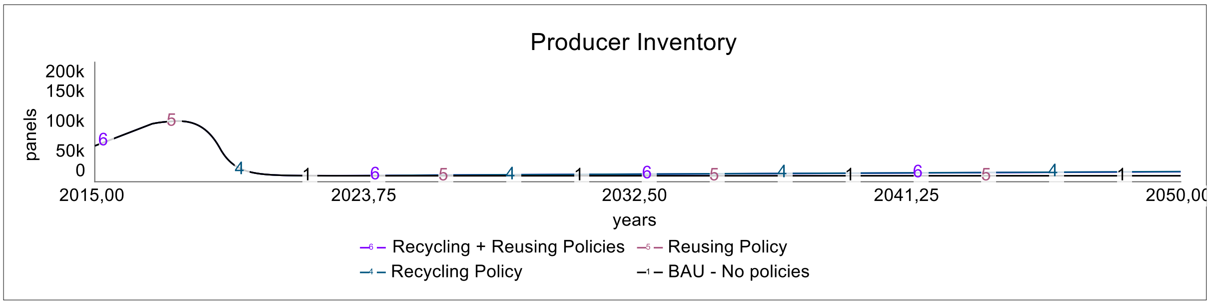

Figure 6.6 – Comparative effect on Producer Inventory.

The fraction reused used was 0.04. A higher fraction of reuse would generally mean a more adopters, but less accumulated installed solar panels. Figure 6.7 below shows the effect of the fraction reusing on adopters, while figure 6.8 illustrates the effect on accumulated installed solar panels.

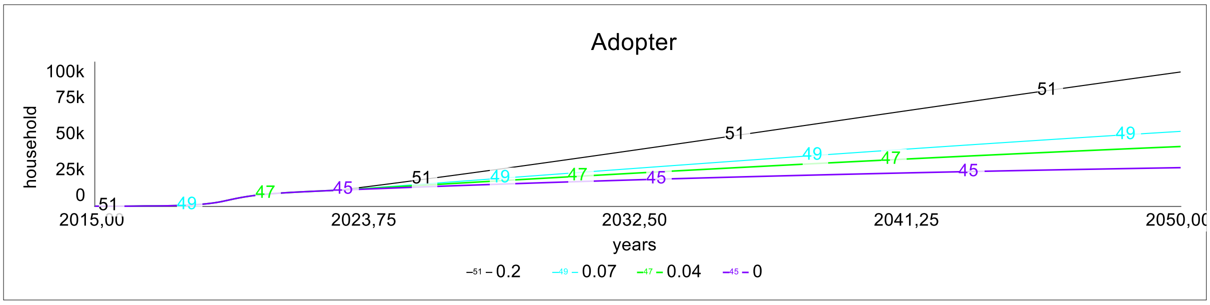

Figure 6.7 – effect of fraction reusing on adopters.

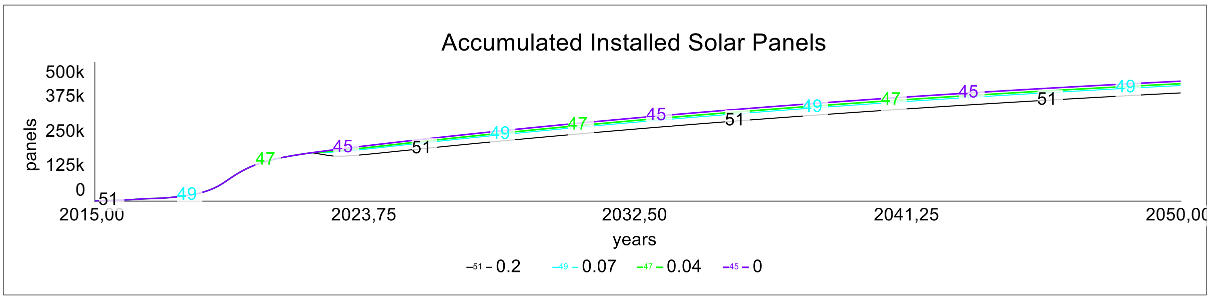

Figure 6.8 – effect of fraction reusing on installed solar panels.

What is interesting here is there are more adopters with a reuse policy, but less installed panels. In fact, by reusing panels, the *accumulated installed solar panels* are decreased by the outflow of *reused panels*. However, comparing the fraction of 0.2 to fraction of 0, the outflow is considerably larger in the first fraction to the other and therefore, the installed solar panels decrease in the beginning of the policy. The capacity to install increases by a higher fraction and the *supplier inventory* is much higher. This is illustrated in figure 6.9.

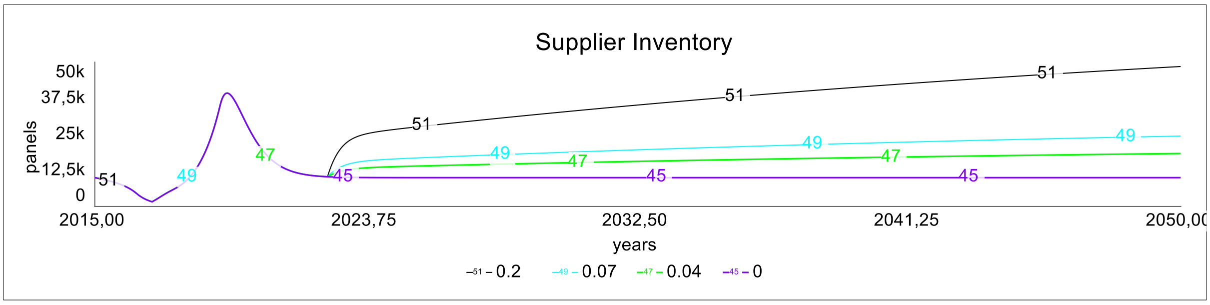

Figure 6.9 – Supplier Inventory.

The higher fraction also causes changes in the drivers of adoption. This is illustrated in 6.10 below. The loop from reusing panels (R3) increases the supplier inventory and the supplier capacity, eventually increasing the adoption rate and consequently the adopter stock. With more adopters, there are a stronger Word-of-Mouth effect, as well, which is the reason from a higher fraction becoming willing to adopt. The values of the drivers are, however, the same.

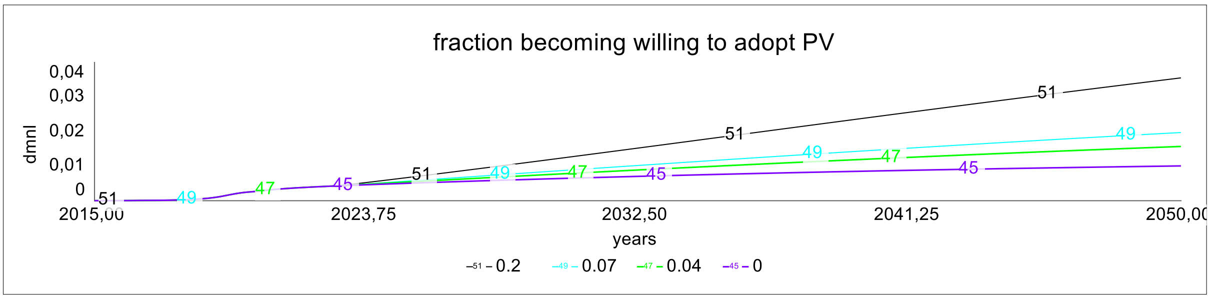

Figure 6.10 – effect on fraction becoming willing to adopt from reusing policy.

On the other hand, recycling of panels is done in countries who has had solar panels for longer than Norway; it is however quite new recycling process. While as much as 95% of the material can be recycled, most solar panels are still mostly landfilled, according to one news article (Sharma and Powell, 2022). In the recycling policy, it is assumed that only 10% of the panels is recycled with an efficiency of 95% as stated above. The overall effect of recycling panels on adopters increases with more recycling, simply because there are more materials to build new panels. Solar panels are considered electrical equipment and will by law need to be handled as such after end of life. Therefore, the *fraction recycled* is the part of all recycled solar panels that are used for solar panel production again, the rest are recycled into other products, not necessarily solar panels. The actual number for this is not known and therefore assumed conservatively to avoid an overly stated effect of the recycling policy scheme.

As with the other policy, the goal is to increase the capacity of the supply-side, so that the demand of the adopters can be satisfied by the suppliers. Figure 6.11 below shows the development of adopters with the different combinations of policies. As seen, the best combination of the inventory policies is having both the recycling and the reusing scheme.

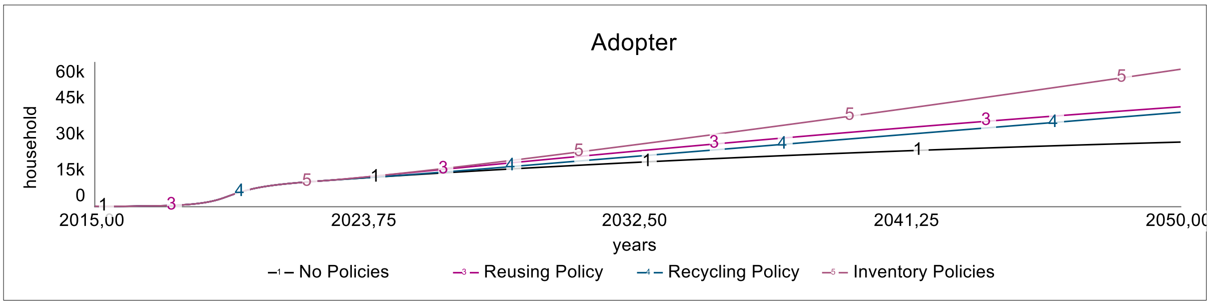

Figure 6.11 - Effect of policies on adopters of solar panels.

Notably, with the recycling and reusing in combination, it is the recycling loop (R4) that drives the behaviour. With more recycling and reusing, there is considerably more capacity and thus more adopters.

6.3 Combined Inventory and Hiring Policies

Combining the two policies are ideal, because one policy without the other restrains the development of adopters, even in the inventory policy that too some degree is effective on its own. In combination, the goal is the increase more installers when it is needed while balancing the inventory.

Parameter	**Value**
Fraction Hiring	0.07 dmnl/year
Inventory: Fraction Reusing	0.05 dmnl/year
Inventory: Fraction Recycling	0.1 dmnl/year

Table 6.3 – Parameters for the Combined Policies.

Figure 6.12 below illustrates the different impact of the policies on adoption. Combining the inventory policies and the hiring policy has the same impact, meaning the hiring policy does nothing, a conclusion also made in section 6.1 about the hiring policy. The reasoning is similar to the hiring policy where there are too many installers already compared to the inventory. Choosing to implement the hiring policy therefore not useful to increase the capacity of the supply-side and is not cost-effective.

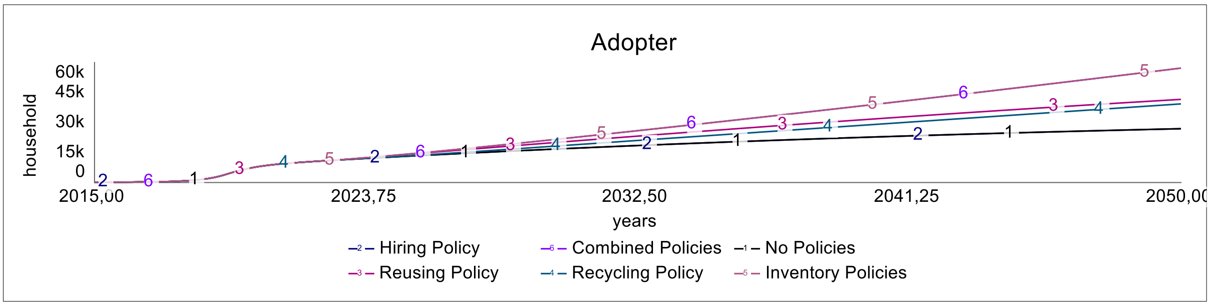

Figure 6.12 – Impact of policies on adopters.

When all policies are implemented (figure 6.12), both inventory policies and hiring policy, there are three reinforcing loops driving the behaviour of the adopter. The first two loops are the same as in the simulation chapter, where the first loop (R2) is dominant if the demand is lower than the capacity (figure 6.13 below). After that, R1 is dominant until the policies are implemented in 2022.

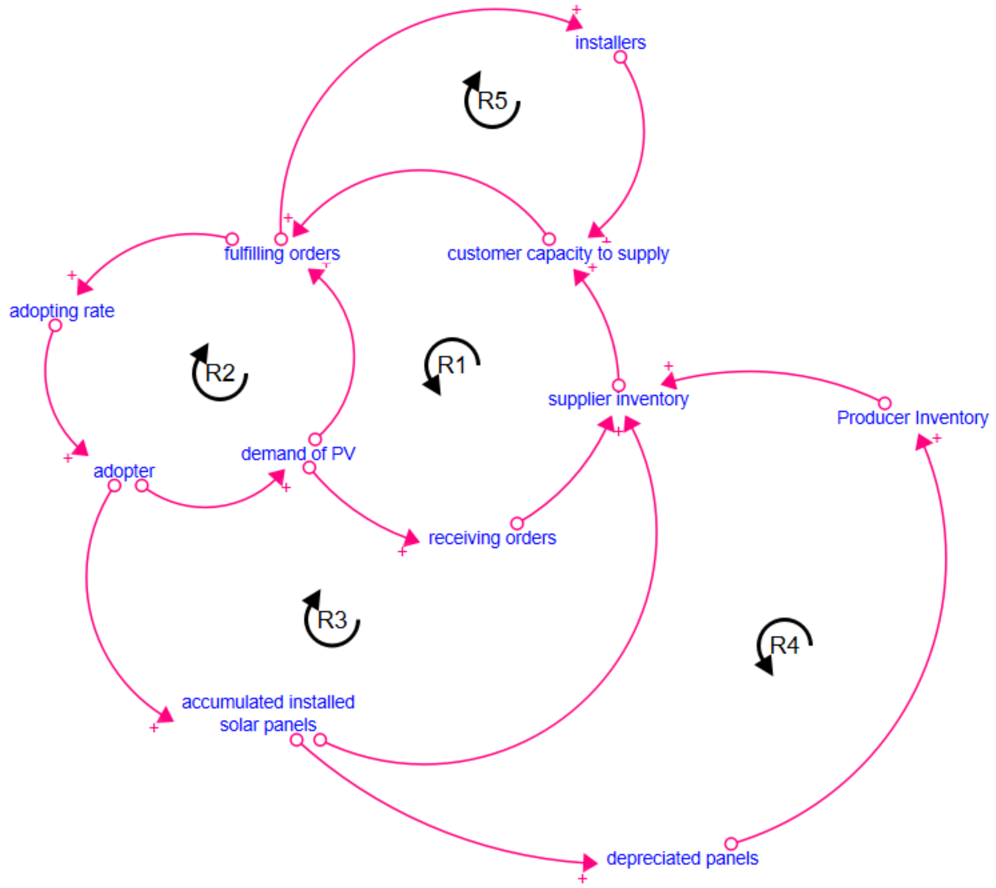

Figure 6.13 – Policy Loops.

Loop R4 (recycling loop) then dominates the increase of adoption of solar panels when all policies are active, but only after implementation in 2022. This is the same pattern of loops as for the inventory policies. As was seen in figure 6.12, the adopters are the same with the combined policies and the inventory policies.

6.4 Reflection on Policy Options

Most policies will come with trade-offs and considerations. Some are effective but could be more expensive than it is impactful. In this part, I will discuss and reflect on potential implementation issues that could affect the policies.

6.4.1 Hiring Policy Option

The first policy option was the hiring policy. The policy had poor impact on the adopters because of the supplier inventory.

Implementing the policy would be of little use because it is not here the issue of capacity lays in the simulation. Hiring beyond the capacity would mean paying wages for installers not working which would expensive. In the normal run of the simulation, there is already 200 000 more installers than needed should the supply continue as low in the future (this is, however, difficult to predict). There are other options. Installers would not necessarily be employed by a supplier, but may opt for using self-employed doing various work, not just solar panel installation. This would solve suppliers' problems of hiring to many installers per the policy, while the self-employed are not just working on solar panels.

Nevertheless, in the second scenario of the simulation chapter (ideal production rate scenario), there are too few installers already after 2020. A hiring policy would most likely be more impactful in this scenario because the installers are scarce. Therefore, should there have been an ideal production rate scenario, there are potential issues with the implementation. Firstly, are potential workers interested in the work? A student from a vocational school is required to complete a two-years apprenticeship where they will learn the necessary skills but may not be interested or know about the option. They cannot be forced into the work but including solar panel installation in the curriculum might introduce solar panels installation as an option. Additionally, if not completely relying on vocational schools to educate installers, are there other people interested in re-training for the work? Already in 2016 was there a solar panel company providing courses in installation of solar panels (Nilsen, 2016a), in addition to a current regular two-day course from a different company (Solarschool, 2021). The option is there, but should the need for more installers come suddenly, as in the ideal production rate scenario, it might not be quick enough. In the simulations, it is easy to “turn on” the policy and increase the yearly fraction of installers, but this development will not occur in reality.

Nonetheless, even if there are enough interested people to do the work, there needs to be a balance between how many are hired and how much work there are. In the model simulation, the overall capacity of the installers is higher than the availability of the inventory to supply. This would mean installers not working, an economic issue for suppliers in companies where installers are hired to the company and, of course, a issue for an installer potentially facing job loss.

6.4.2 Inventory Policies

Policy option two concerns two policies: one for reuse of panels, while the other for recycling, in addition to the policies in combination.

The first potential issue relates to procedures. As solar panels are considered electrical equipment it will have to be recycled per legislation in Norway. Very little specific information about recycling of solar panels is available in Norway beyond a responsibility to recycle. The policy of recycling and using for new solar panels would involve a multi-step procedure of shipping, de-assembling and assembling; the process might be long. The question then becomes, are the procedures in place to handle, not just solar panels from Norway, but from any other country in Europe where adoption of solar panels has already started? A guarantee that all solar panels recycled becomes new solar panels might be difficult.

Further, even with procedures for how this should work, are the recycling technology ready and cost-effective enough for it to be sensible to implement the technology? Recycling can be expensive and energy intensive. It would not make sense to implement the technology if the recycled panels are too expensive or uses to much energy, especially if the energy comes from fossil fuels. The cost has not been accounted for in the model but should certainly be considered in the implementation of the policy.

As for reuse of panels, the panels still need to be of a certain quality to sell to the next person and why would people be selling their still functioning solar panels? The market may not be as big as the result in the policy simulation. Observations from solar panels groups on social media does sometimes show that there are people selling their panels after they have received them, but before they were installed, but most likely, someone who has bought panels will probably not sell them unless dissatisfied. However, it illustrates that the potential is there and could be a potential option.

There could possibly be a need for some procedures for re-selling. The solar panels need to be of a certain quality, considering the efficiency of solar panels decreases with time. The panels need to be sold, transported, possibly fixed or cleaned, before installed again. Any of these steps are multifaceted. Of course, the re-selling could possibly be a private market between individual to individual, but with the implication that there is no guarantee for the buyer in terms of quality of the solar panels.

6.5 Summary of Policies

In the context of increasing adopters of solar panels in Norway, the hiring policy of increasing skilled installers are not impactful. While installers could be a constraint of adoption, the BAU scenario found that the primary constraint was the availability of solar panels rather than installers. The hiring policy does not address this issue. To increase adopters of solar panels it is therefore more impactful to implement an inventory policy with recycling and reusing of solar panels. A combination of the mentioned policies is also possible, however, there were no difference in impact between combined and inventory policies. The hiring and combined policy would only be useful in situations where there are enough solar panels and would not be cost-effective in the context. The implementation of any of the policies are not straightforward.

Chapter 7 CONCLUSION

This chapter summarizes and answers the research questions asked in the introduction of the thesis. The topic of the thesis was diffusion of solar panels in Norway and its interaction with the suppliers of solar panels. I have identified three population groups: the adopter, potential adopter, and non-adopter of solar panels, and focused on the adopter group and what has driven the adoption. This chapter summarizes and answers the research questions asked in the introduction of the thesis. The research questions asked in this thesis has been:

What has driven the diffusion of solar panels in Norway and how are the current suppliers managing the current state of solar panel investments?

With the sub-questions:

- How does the non-adopter, potential adopter and adopter differ?
- Which policies are currently in place, how are they performing and what could be other possible policies?
- What is the role of suppliers in the current market?
- What are the biggest barriers of the suppliers of solar panels?

These questions will be answered and summarized in section 7.1. Section 7.2 introduces the main limitations of the research, while section 7.3 introduces potential further research.

7.1 Summary of Findings

Due to various reasons, Norway has seen an unprecedented increase in electricity prices. In a response to this increase, individuals have explored alternative options to electricity – specifically by adopting solar panels to supplement their own electricity needs and becoming prosumers. This has led to a high demand for solar panels and a subsequent difficulty of the suppliers to supply solar panels. The drivers of diffusion are, however, varied and transcends economic factors alone.

In literature, drivers such as the economic benefit of adoption, motivation for self-sufficiency, environmental performance and the knowledge of the performance of the solar panels has been reported to be significant. The first driver, economic benefit of adoption, is an interplay between the price of the technology, the income, and potential savings on the electricity price. In Norway, the economic benefit is increased by a grant by Enova, aiding in the investment of solar panels. Depending on these factors, the economic benefit of adoption will either increase or decrease. The economic benefit of adoption is widely discussed, both in literature and online, and frequently acts as a barrier for adoption due to the high prices.

However, many will see the benefit of adoption. It allows for some self-sufficiency, using less of centralised electricity sources and having more power over their own use. With the recent increase of electricity prices, this has become an important driver. Further, literature often states the environmental performance to be important and the information about the performance of the solar panels. This was less observed online, however, this could be because the current adopters are investing in solar panels because of the electricity prices, more than for the environment. The last driver, knowledge of performance, is significant, as knowing that solar panels do function in Norway is a given.

The adopter of solar panels are the ones who have realized this and already adopter. They are often environmentally aware and sees the technology as a contribution to the energy system; especially the earlier adopters will often have had a fair interest and knowledge about the performance of the solar panels. The potential adopter, however, are somewhat knowledgeable, but curious about the technology, in contrast to the non-adopter who lacks trust in the technology and perceive the adoption of solar panels to be risky. The potential adopter has overcome this and could potentially be driven to adopting by any of the drivers.

Yet, adoption of solar panels is not only influenced by these drivers. In fact, the simulation revealed that the drivers on the demand-side is less important. Adoption of solar panels is an interaction between the supply-side, whose role is to supply and install the solar panels, and the demand-side of adopters. When the supply-side is limited by the available solar panels and installers, the adoption rate will not increase beyond the constraint and consequently the drivers are useless irrespective of how motivated a potential adopter is for self-sufficiency or how knowledgeable of solar panels they are.

The model output demonstrated issues in the supply of solar panels. However, the availability of installers could also have been the constrain of the development of adopters. The sudden increase in demand has happened quicker than the ability of the supplier to supply the customer and hence, they are experiencing difficulties in supplying solar panels. The supply-side is, in other words, not managing the desire of potential adopters to adopt. Most behaviour of solar panels is therefore driven by the how much the suppliers can supply, rather than the drivers in the simulation.

In the BAU scenario, the demand is initially satisfied in the first two year, but from 2017 the capacity is lower than demand and hence the backlog starts increasing. At this point, the suppliers have a desired shipment to inventory which is delivered by the producer of the solar panels. As the producer cannot deliver after a while, the increase to the inventory is constrain by what producers can manage. There were no problems with the availability of installers in this scenario, however, this depends on the balance between the inventory, the number of installers and their capacity to install – all uncertain in numbers and calibrated. Should the initial number of available installers or the capacity to install solar panels be wrong, then the capacity of the installer might be overestimated. The constrain could be on the installers at some point.

This happened in the ideal production rate scenario. After a while there would be too few installers because the production of solar panels would be equal to the desired shipment to inventory. The installer loop (R4) would constrain the development after 2019 while the capacity of the supplier is much higher. In this scenario, it would be useful with a hiring policy as opposed to the BAU scenario who experienced no constraints on installers. The most impactful policies would be on the supply-side, but what policy or combination of policies depends on the scenario. As said, hiring would be useless in the BAU scenario, as there was no constraint. Having any of the inventory policies – either recycling or reusing or both – would be more impactful on the adoption rate.

Learning from the model output, there is little point implementing demand-side policies before the capacity issues are addressed. While the demand-side policies can be useful in the beginning stages with no capacity issues, they will cease functioning when the demand exceeds the capacity because suppliers cannot supply. The most important loops to drive behaviour of the system, were on the supply-side, because the capacity was lower than the demand. However, should there be enough capacity, it is mainly the economic benefit loop that will increase the adoption. In Norway, the Enova grant has been helping potential adopters to adopt and per sensitivity analysis, it has been impactful, but after the capacity issues, the most impactful policies will be on the supply-side of solar panels adoption. The implication of the policy for a country wanting to increase their adopter population, is that it is not worthwhile implementing policies on the demand-side if there are capacity issues on the supply-side.

7.2 Limitations

One major limitation has been the time constraints and is the main reason why the interview size was low, a major limitation for the quality of the research. Many suppliers were busy at the time of contact and if agreeing to interview, only had time in December or later.

This resulted in the second limitation, the model structure on the supplier-side could possibly have been significantly improved by more interviews, especially knowing I would have changed the questions after the first round. Unfortunately, the time was not there. While the structure is basic, it is sufficient for experimenting with the effect of different production rates, to understand how it affect the adopting rate.

7.3 Further research

Two ideas for further research were generated in the making of this thesis. Firstly, a general mapping of the supplier sector in Norway would be helpful to build model structure more specifically to better know how it could potentially develop over the next decades. The structure as it is, is very simple and would most likely be improved by more supplier interviews or similar data collection methods to understand the decision-rule of the supply-side. Perhaps even group model building would be useful to create a shared understanding of the supplier-side between different actors on the supply-side. Additionally, having certain numbers for installers, their capacity to install and inventory would have made the development of the thesis easier. As of now, most have been used to calibrate to historical data.

A further research idea would be to continue the research on the different characteristics of the adopter, potential adopter, and the non-adopter population groups. This is useful for countries that are looking to learn what causes adopting of solar panels and could aid in understanding the different population groups. Understanding the reasons why some are or are not adopting could therefore be useful to increase the adoption rate, especially in countries needing to further decarbonise their energy system. As of now, my observations of 20 comment sections are still very basic and could improve from more research. In addition, many diffusion papers on energy technology will focus on two of the three population groups while mentioning the last, but rarely all three with some exceptions, like Balcombe, Rigby and Azapagic (2014). This can be used to identify a potential adopter or to find solutions for the potential adopter that works best for them in cases where there are reasons they cannot adopt even when desiring it.

A more in-depth analysis of the different population groups could potentially change the model in structure and thus the behaviour.

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APPENDIX A: Interview Guides

The guides consist of main questions and sub-questions that were asked if/when appropriate. Additionally, some open questions were asked to clarify or continue interesting points. The latter were not recorded in the guide.

A.1 Prosumer

Who are you?

1. How long have you been a prosumer?
2. Talk a little bit about the technical stuff, how many panels are in your system?
3. How much installed capacity
4. How much (typically) do you generate?

How has your experience been?

Can you talk me through the process of acquiring from start to finish?

1. Why then?
2. How long did it take to acquire?
3. Which actors were you in contact within this process?

Can you talk about your main reasons for choosing PV?

1. What influenced you to make this decision to invest?
2. Most important?
3. Do you know others who use panels? Before/after you?

Why invest? Why not invest?

4. How do other people perceive PV?
5. What do you say about it?
6. Why should others invest?

Did you use Enovas economic aid?

(**If yes**), how did you experience that?

(**If no**), how did you finance the investment? Yourself/other?

Anything else you would like to add before we end the session?

A.2 Supplier

How long have you been working on solar?

Can you start a little bit to talk about the company you are from and what you do?

1. PV: what are the main tasks?
2. When did you start?
3. Why PV?

How do you experience competition with other companies?

4. how many could you "help" in a year?
5. any constraints/backlog?
6. much interest?
7. Possible to "only" do household solar?

What would resilience in this market mean to you?

How does the process go?

8. Can you show estimates of cost, (installation + the technology + other costs?)
9. How long does it take from interest, to ordering, to getting the panels, to instalment?
10. How many panels?

Do you have any thoughts about the types of customers?

11. Have they changed in characteristics since the beginning?

What do customers say? Do you have an understanding of their most important drivers of buying PV?

12. IF green only, why do they choose you over a cheaper supplier?
13. IF money, why do they choose you?

How would you talk to a customer who was interested? What do you say?

14. About potential.
15. About cost.

So, maybe a bit early to ask, but do you think people would re-invest or buy new panels/take panels with them (if possible) if they move?

16. What makes a happy customer? Or an unsatisfied customer.

How has the cost developed? Can you show me (cirka) how it has developed over time?

q. Most important reasons for the any changes

(**if learning is mentioned**): I am interested in the different learning processes of the company, do you have any thoughts on that?

1. Any cooperation with others?
2. Learning effect on price

(If they provide instalments) Who is doing the installing?

r. specialised people or learning as they work?
s. How long does it take to have a fully efficient installer? What does this process ensue?

Åpenhetsloven - implications for you or too small? How do you view it?

Do you do marketing/how do customers find you?

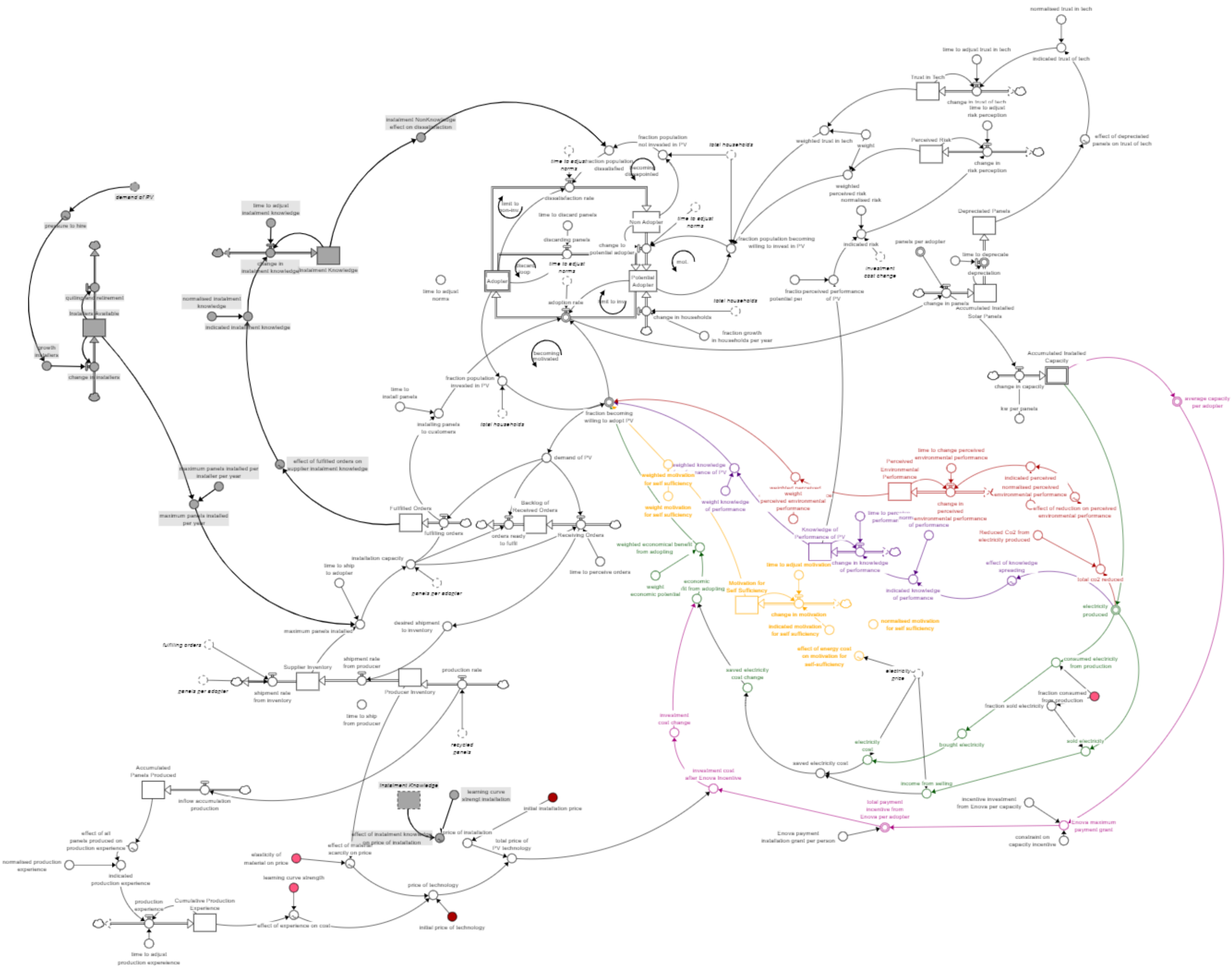
Where do you see the market go in the future?

t. What is ideal?
u. What might mean problems?

I understand suppliers have some responsibilities of disposing of panels - what are the procedures after panels stop working?

Anything else useful that you would like to add?

APPENDIX B: Full Model



B.1 – Full Model.

APPENDIX C: Documentation

Total	Count	Including Array Elements
Variables	181	181
Sectors	8	
Stocks	19	19
Flows	29	29
Converters	133	133
Constants	64	64
Equations	98	98
Graphicals	13	13
Macro Variables	11	

	Equation	Properties	Units	Documentation	Annotation
initial_adopters	200		house hold		
initial_non_adopter	1250000		house hold		
initial_potential_adopter	1250000		house hold		
Adoption:					
Adopter(t)	Adopter(t - dt) + (adoption_rate - discarding_panels - dissatisfaction_rate) * dt	INIT Adopter = initial_adopters	house hold	This stock represents the adopters of solar panels in Norway. The unit is people. It is depleted by two flows: the dissatisfaction rate representing persons that do not wish to reinvest for various reasons, and the discard rate representing those that potentially wish to re-invest after the lifetime of the solar panel. It increases by the adoption	NON-NEGATIVE

				rate, which are the persons that are adoption solar panels.	
adoption_rate	MIN(((Potential_Adopter*fraction_becoming_willing_to_adopt_PV)/time_to_adjust_norms); installing_panels_to_customers)		household/years	This flow represents the amount of people that adopt PV panels per year. Its unit is people per year. The flow shows how people go from potential adopters to actual adopters by the demand adoption rate. The adoption rate is constrained by installing panels to customers converter.	UNIFLOW
change_in_households	total_households*fraction_growth_in_househoIds_per_year		household/years	This flow represents the change in population. Its unit is person per year. The flow increases the non-adopter population, assuming	UNIFLOW
change_to_potential_adopter	(Non_Adopter*fraction_population_becoming_willing_to_invest_in_PV)/time_to_adjust_norms		household/years	This flow represents the people who become potential adopters when technology improves, e.g., by efficiency of the solar panels. The unit is people per year. The flow depends on the non-adopters in the population and the fraction improvement in technology per year. While there are probably more than technological improvements that can make a non-adopter into a potential adopter, we assume that it is technology that separates a non-adopter from being a potential adopter.	UNIFLOW
discarding_panels	Adopter/time_to_discard_panels	OUTFLOW PRIORITY: 1	household/years	This outflow represents solar panels discarded as they reach their lifetime. Its unit is household per year. Solar panels do not work forever. When adopters are	UNIFLOW

				discarding their panels, they become potential adopters again, assuming they would be willing to re-purchase solar panels.	
dissatisfaction_rate	(Adopter*fraction_population_dissatisfied)/time_to_adjust_norms	OUTFLOW PRIORITY: 2	household/years	This flow represents the households not satisfied with their investment. Its unit is household per year. The flow is an outflow from adopters and into non-adopters and represents does who have by any reason not been happy with their investment.	UNIFLOW
fraction_becoming_willing_to_adopt_PV	fraction_population_invested_in_PV*(weighted_economical_benefit_from_adopting+weighted_knowledge_of_performance_of_PV+weighted_motivation_for_self_sufficiency+weighted_perceived_environmental_performance)		dmnl	This converter represents the demand of solar. Its unit is person per years. It differs from the adoption rate, assuming that a certain number of people may desire to adopt solar panels, but do not necessarily do so, because of constraints in the supply chain. This converter, however, show how many actually wants the technology.	
fraction_growth_in_households_per_year	0,001		dmnl/year	This converter represents the growth in the population per year. The unit is dimensionless per year.	
fraction_population_becoming_willing_to_invest_in_PV	(Potential_Adopter/total_households)*(weighted_trust_in_tech+weighted_perceived_risk)		dmnl	This converter represents the fraction becoming willing to invest. Its unit is dimensionless. It is affected by the density of potential adopters to all household and the drivers of becoming potential adopters.	
fraction_population_dissatisfied	fraction_population_not_invested_in_PV*instalment_NonKnowledge_effect_on_dissatisfaction		dmnl	This converter represents the fraction becoming dissatisfied. Its unit is dmnl. The equation represents the WOM-effect of non-adopters	

				on adopters and the dissatisfaction rate. A higher WOM-effect would increase this converter, while if non-adopter depletes, it will also decrease.	
fraction_population_invested_in_PV	Adopter/total_households		dmnl	This converter represent the fraction population invested in solar panels. Its unit is dimensionless. This converter is a density of adopters, saying with more adopters, it is more likely that other people might adopt. It works as a WOM-effect.	
fraction_population_not_invested_in_PV	(Non_Adopter/total_households)		dmnl	This converter represents the WOM-effect of non-adopter on the adopter. A higher density of non-adopter to households, mean higher effect on the dissatisfaction.	
fraction_potential_perceived	0,5		dmnl	This converter represents how much of the knowledge is perceived by a non-adopter to become a potential adopter. Observed is that a potential adopter must have perceived some information to become a potential adopter. They also actively ask for information.	
indicated_risk	normalised_risk*investment_cost_change*perceived_performance_of_PV		dmnl	This converter represents the indicated risk and is affected by the cost and how much knowledge about perceived performance of solar panels.	
installing_panels_to_customers	DELAY(fulfilling_orders; time_to_install_panels)		household/Years	This converter represents the customers who have had their solar panels installed. Its unit is household per year. It acts as the final constraints on adoption by delaying the fulfilling orders flow by the time it takes to install solar panels.	

instalment_NonKnowledge_effect_on_dissatisfaction	1-Instalment_Knowledge		dmnl	This converter represents the lack of knowledge.	
Non_Adopter (t)	Non_Adopter(t - dt) + (dissatisfaction_rate - change_to_potential_adopter) * dt	INIT Non_Adopter = initial_non_adopter	household	This stock represents the non-adopters in the population. The unit is people. The stock is depleted by the flow of people going who become potential adopters due to changes in technology. We assume that there will always be people that cannot adopt solar panels due to technological inefficiencies. However, an increase in efficiency may make non-adopters to potential adopters. The stock is increased by a change in population and by the dissatisfaction rate from adopters. In other words, all increase in the population will become non-adopters. Additionally, all dissatisfied prosumers who choose not to invest in solar panels again, become non-adopters.	NON-NEGATIVE
normalised_risk	0,5		dmnl	This parameter represents normalised risk. It is assumed to start at 0.5.	
perceived_performance_of_PV	Knowledge_of_Performance_of_PV*fraction_potential_perceived		dmnl	This converter represents the perceived performance of solar panels. Its unit is dimensionless. When potential adopters perceived information about performance, it also become less risky, as many non-adopters do not become adopter because it seems risky.	
Potential_Adopter(t)	Potential_Adopter(t - dt) + (discarding_panels +	INIT Potential_Adopter =	household	This stock represents people that are potential adopters. The unit is people.	NON-

	change_to_potential_adopter + change_in_households - adoption_rate) * dt	initial_potential_adopter		All people that live in an area that can use solar panels will be called potential adopter. It is increased when more people become potential adopters due to change in technology. In other words, potential adopter is assumed to be any person who could reasonably adopt solar panels. The stock is also increased by the discard rate of the invention. When an adopter discards of the solar panels, they become potential adopters again unless they were dissatisfied with the invention. It is depleted by the flow adoption rate which is the people that choose to adopt the invention.	NEGATIVE
time_to_adjust_norms	0,2		Years	This parameter represents the time it takes to change norms. Its unit is years.	
time_to_discard_panels	30		years	This converter represents the time to discard the solar panel. Its unit is in years. Generally, a solar panel lasts around 30 years. However, some sources states the lifetime between 25 to 40 years (Walker, 2022).	
time_to_install_panels	1/52		Years	This parameter represents the time it takes to install panels. Its unit is years. It is assumed to be around a week.	
weight	0,5		dmnl	This is the weight between risk and trust.	

weighted_perceived_risk	(1-Perceived_Risk)*(1-weight)		dmnl	This converter represents the perceived risk in investing in solar panels.	
weighted_trust_in_tech	Trust_in_Tech*weight		dmnl	This converter represents the weighted trust in the technology. Its weight is assumed 0.5 with equal weight between risk and trust.	
Calculation:					
Accumulated_Capacity_Norway_Data	GRAPH(TIME) Points: (2015,000, 120), (2016,000, 457), (2017,000, 2630), (2018,000, 20713), (2019,000, 67559), (2020,000, 105799), (2021,000, 150021), (2022,000, 248625)		kW	Data from (Øvrebø, 2022). Converted from mW to kW.	
"data_adopters_2015-2022"	GRAPH(TIME) Points: (2015,000, 200), (2016,000, 700), (2017,000, 900), (2018,000, 1000), (2019,000, 4067), (2020,000, 5838), (2021,000, 7792), (2022,000, 12207)		person	Data points for 2015, 2016, 2018 (2017 unknown) (Westskog *et al.*, 2018; NVE, 2022b).	
Demand_Drivers:					
average_consumption	20000		Kw*hours/household/years	This parameter represents the average consumption per household per years in Norway. The unit is kwh per household per year. Generally, the average consumption in Norway has been between 16 000 and 21 000 in the last decade (SSB, 2018).	
bought_electricity	IF consumed_electricity_from_production < total_consumption		(kW*hours)/Years	This converter represents the bought energy. Its unit is kwh per year.	

	THEN total_consumption-consumed_electricity_from_production ELSE 0				
change_in_knowledge_of_performance	(indicated_knowledge_of_performance-Knowledge_of_Performance_of_PV)/time_to_perceive_performance		dmnl/year	This flow represents the change in knowledge of the performance. Its unit is dimensionless per year. The equation calculates the gap from the actual knowledge to the indicated and increases the stock by a time adjustment.	
change_in_motivation	(indicated_motivation_for_self_sufficiency - Motivation_for_Self_Sufficiency)/time_to_adjust_motivation		dmnl/year	This flow represents the change in motivation. Its unit is dmnl per year. The change in motivation is affected by the electricity prices, saying with a higher price, a potential adopter is more willing to adopt.	
change_in_perceived_environmental_performance	(indicated_perceived_environmental_performance-Perceived_Environmental_Performance)/time_to_change_perceived_environmental_performance		dmnl/year	This flow represents the perceived environmental performance. Its unit is dimensionless per year. It is affected by how much co2 is saved by producing their own energy.	
constraint_on_capacity_incentive	20		kw/household	This parameter represents the constraint on the capacity grant. Its unit is kW per household. An adopter will only receive grant per kW until 20 kW installed. Anything after that is fully paid by the adopter themselves (Enova, 2022).	
consumed_electricity_from_production	electricity_produced*fraction_consumed_from_production		(kW*hours)/Years	This converter represents the consumer electricity of their own production. The unit is kWh per year. It depends on the fraction	

				consumed from production and how much electricity is produced.	
economic_benefit_from_adopting	saved_electricity_cost_change-investment_cost_change		dmnl	This converter represents the economic benefit that the adopters perceive. Its unit is dimensionless. The economic benefit comes from the change in cost in adopting and the income from selling.	
"effect_of_energy_cost_on_motivation_for_self-sufficiency"	GRAPH(electricity_price/INIT(electricity_price)) Points: (0,000, 0,000), (0,200, 0,02526), (0,400, 0,08682), (0,600, 0,2331), (0,800, 0,5352), (1,000, 1,000), (1,200, 1,465), (1,400, 1,767), (1,600, 1,913), (1,800, 1,975), (2,000, 2,000)		dmnl	This graphical function represents the effect of energy cost on self-sufficiency. Its unit is dmnl. At 1, it takes the normalised motivation. Should it go below 1, but decreasing prices, then motivation decreases. If it goes above, because of high prices, it increases.	
effect_of_knowledge_spreading	GRAPH(electricity_produced/INIT(electricity_produced)) Points: (0,000, 0,000), (0,200, 0,200), (0,400, 0,400), (0,600, 0,600), (0,800, 0,800), (1,000, 1,000), (1,200, 1,200), (1,400, 1,400), (1,600, 1,600), (1,800, 1,800), (2,000, 2,000)		dmnl	This graphical function represents the effect of electricity produced by the adopters on the knowledge of the performance of solar panels. Its unit is dimensionless.	
effect_of_reduction_on_perceived_environmental_performance	GRAPH(total_co2_reduced/INIT(total_co2_reduced)) Points: (0,000, 0,000), (0,200, 0,02526), (0,400, 0,08682), (0,600, 0,2331), (0,800, 0,5352), (1,000, 1,000),		dmnl	This graphical function represents the effect total co2 reduced on perceived environmental performance. Its unit is dmnl. At 1, it takes the normalised environmental performance. Should it go below 1, but	

	(1,200, 1,465), (1,400, 1,767), (1,600, 1,913), (1,800, 1,975), (2,000, 2,000)			decreasing prices, then motivation decreases. If it goes above, because of high prices, it increases.	
efficiency_of_panels	0,16		dmnl	This parameter represents the efficiency of the panels. Its unit is dimensionless and is typically between 16-20% (Otovo, 2022). The value is set to 16%.	
electricity_cost	bought_electricity*electricity_price		NOK/year	This converter represents the electricity cost per year. Its unit is NOK per year. The electricity cost increase for three reasons: either an increase in electricity price, buying more electricity or the combination of these two.	
electricity_produced	Accumulated_Installed_Capacity*peak_hours*efficiency_of_panels		(kW*hours)/Years	This converter represents the kilowatt-hours produced per adopter based on the peak house per year. The unit is kWh per person per year. It depends on how much capacity has accumulated, peak sun hours and the efficiency of the panels.	
Enova_maximum_payment_grant	MIN(incentive_investment_from_Enova_per_capacity*average_capacity_per_adopter; constraint_on_capacity_incentive*incentive_investment_from_Enova_per_capacity)		NOK/household	This converter represents the full Enova grant for capacity. Its unit is NOK per household. The equation is a MIN-function where the paid amount is based on how many kW the average adopter has installed multiplied with how much they get per kW. If, however, the average amounts to more than 20 kW, it will only calculate from that. In short, it takes the minimum calculation of the two equations within the MIN-function.	

Enova_payment_installation_grant_per_person	7500		NOK/household	This parameter represents the grant received from Enova for installation. Its unit is NOK per household. The instalment grant is 7500 NOK.	
fraction_consumed_from_production	0,92		dmnl	This parameter represents the fraction consumed from production. Almost of all electricity is usually consumed by the adopter because this reduces some of the fees included in electricity prices. Value set to 0,9.	
fraction_sold_electricity	(1-fraction_consumed_from_production)		dmnl	This converter represents the fraction sold electricity. The unit is dimensionless. It depends on how much electricity is consumed by the adopter.	
incentive_investment_from_Enova_per_capacity	2000		NOK/kw	This parameter represents the grant received from Enova per kW installed. Its unit is NOK per kW. The grant is 2000 NOK per kw installed.	
income_from_selling	sold_electricity*electricity_price		NOK/year	This converter represents the income from selling electricity. The unit is NOK per year. Income from selling electricity is calculated on how much is sold and the electricity price.	
indicated_knowledge_of_performance	normalised_knowledge_of_performance*effect_of_knowledge_spreading		dmnl	This converter represents the indicated knowledge of the performance of the solar panels. Its unit is dimensionless.	
indicated_motivation_for_self_sufficiency	"effect_of_energy_cost_on_motivation_for_self-sufficiency"*normali		dmnl	This converter represents the indicated motivation for self-sufficiency. Its unit is dimensionless.	

	sed_motivation_for_self_sufficiency				
indicated_perceived_environmental_performance	normalised_perceived_environmental_performance*effect_of_reduction_on_perceived_environmental_performance		dmnl	This converter represents the indicated perceived environmental performance. It is increased by the effect of reduction on environmental performance.	
investment_cost_after_Enova_Incentive	total_price_of_PV_technology-total_payment_incentive_from_Enova_per_adopter		NOK/household	This converter represents the investment cost after the Enova incentive grant. Its unit is NOK per household. The equation shows how much the adopter will have paid after receiving the grant from Enova.	
investment_cost_change	(INIT(investment_cost_after_Enova_Incentive)-investment_cost_after_Enova_Incentive)/INIT(investment_cost_after_Enova_Incentive)		dmnl	This converter represents the change in cost over the time period. Its unit is dimensionless. Essentially, it calculates the percentage in the change of cost. The equation takes the initial price (high) minus the later price (lower) and finds the gap between the two, and divides by the initial price. The benefit is in this decrease of cost.	
Knowledge_of_Performance_of_PV(t)	Knowledge_of_Performance_of_PV(t - dt) + (change_in_knowledge_of_performance) * dt	INIT Knowledge_of_Performance_of_PV = 0,5	dmnl	This stock represents the knowledge of performance of solar panels. Its unit is dimensionless. It increases by the inflow of change in knowledge of performance.	NON-NEGATIVE
Motivation_for_Self_Sufficiency(t)	Motivation_for_Self_Sufficiency(t - dt) + (change_in_motivation) * dt	INIT Motivation_for_Self_Sufficiency = 0	Dmnl	This stock represents the motivation for self-sufficiency.	NONNEG

					ATIVE
normalised_knowledge_of_performance	0,5		Dmnl	This parameter represents the normalised knowledge of performance. Its unit is dimensionless.	
normalised_motivation_for_self_sufficiency	0,5		Dmnl	This represents the normalised motivation for self-sufficiency. Its unit is dimensionless.	
normalised_perceived_environmental_performance	0,5		Dmnl	This parameter represents the normalised perceived performance and is set to 0.5.	
peak_hours	700		hours /years	This converter represents the peak hours per year. The unit is hours per years. It is typically between 650 and 800 hours per years in Norway (Lie, 2016).	
Perceived_Environmental_Performance(t)	Perceived_Environmental_Performance(t - dt) + (change_in_perceived_environmental_performance) * dt	INIT Perceived_Environmental_Performance = 0,5	Dmnl	This stock represents the perceived environmental performance.	NON-NEGATIVE
Reduced_Co2_from_electricity_produced	0,128/4000		Co2 eqv/(kW*hours)	This represents the amount of co2 reduced from producing electricity from solar panels at home.	
reduced_electricity_cost	electricity_cost-income_from_selling		NOK/year	This converter represents how much the adopters save on electricity cost. Its unit is NOK per year.	
saved_electricity_cost_change	(reduced_electricity_cost-INIT(reduced_electricity_cost))/reduced_electricity_cost		dmnl	This converter represents the change in income from selling electricity. Its unit is dimensionless.	

				The equation takes the current price and finds the gap from the initial price and divides by the initial price. This finds the percentage of the increase in income which is the benefit in this case. However, when the electricity price decreases it affects the converter due to lower benefit from income while also having lower electricity costs. This can be seen occurring in 2020 when the electricity prices were lower than the year before.	
sold_electricity	electricity_produced*fraction_sold_electricity		(kW*hours)/Years	This converter represents how much electricity is sold. Its unit is kWh per years.	
time_to_adjust_motivation	1		years	This parameter represents the time it takes to adjust the motivation for self-sufficiency. The unit is years.	
time_to_change_perceived_environmental_performance	1		years	This parameter represents the time it takes to adjust perceived environmental performance. The unit is years.	
time_to_perceive_performance	1		years	This parameter represents the time it takes to adjust the perception of the performance. The unit is years.	
total_co2_reduced	electricity_produced*Reduced_Co2_from_electricity_produced		Co2 eqv/Years	This represents the total co2 reduced (Kristiansen and Lindahl, 2017).	
total_consumption	Adopter*average_consumption		(kW*hours)/Years	This converter represents the total consumption of adopters in Norway.	
total_payment_incentive_from_Enova_per_adopter	Enova_maximum_payment_grant+Enova_payment_installation_grant_per_person		NOK/household	This converter represents the total grant from Enova per adopter. Its unit is NOK/household (Enova, 2022).	

				This is the additive of how much an adopter receives for installation and what an adopter received per kW installed.	
weight_economic_potential	0,25		dmnl	This converter represents the weight of relative importance for economic potential.	
weight_knowledge_of_performance	0,25		dmnl	This converter represents the weight of relative importance for knowledge of performance.	
weight_motivation_for_self_sufficiency	0,25		dmnl	This converter represents the weight of relative importance for motivation for self-sufficiency.	
weight_perceived_environmental_performance	0,25		dmnl	This converter represents the weight of relative importance.	
weighted_economical_benefit_from_adopting	weight_economic_potential*economic_benefit_from_adopting		dmnl	This represents the weighted benefit from adopting. Its unit is dimensionless. It says something about how important one driver is next to another.	
weighted_knowledge_of_performance_of_PV	Knowledge_of_Performance_of_PV*weight_knowledge_of_performance		dmnl	This represents the weighted benefit from knowledge of performance. Its unit is dimensionless. It says something about how important one driver is next to another.	
weighted_motivation_for_self_sufficiency	Motivation_for_Self_Sufficiency*weight_motivation_for_self_sufficiency		dmnl	This represents the weighted benefit self-sufficiency. Its unit is dimensionless. It says something about how important one driver is next to another.	
weighted_perceived_environmental_performance	Perceived_Environmental_Performance*weight_perceived_envi		dmnl	This represents the weighted perceived environmental performance. Its unit is dimensionless.	

	ronmental_performance			It says something about how important one driver is next to another.	
Drivers_Becoming_Potential_Adopter:					
change_in_risk_perception	(indicated_risk-Perceived_Risk)/time_to_adjust_risk_perception		dmnl/year	This flow represents the change in risk perception. Its unit is dmnl per year.	
change_in_trust_of_tech	(indicated_trust_of_tech-Trust_in_Tech)/time_to_adjust_trust_in_tech		dmnl/year	This flow represents the change in trust in technology. Its unit is dmnl per year.	
effect_of_depreciated_panels_on_trust_of_tech	GRAPH(Depreciated_Panels/INIT(Depreciated_Panels)) Points: (0,000, 1,415), (0,200, 1,415), (0,400, 1,400), (0,600, 1,336), (0,800, 1,230), (1,000, 1,000), (1,200, 0,2944), (1,400, 0,149), (1,600, 0,121), (1,800, 0,114), (2,000, 0,092)		dmnl	This graphical function represents the effect of depreciated panels on the trust of the technology. Observed online, is that many non-adopters will be distrusting of the technology and will use the fact that many solar panels is not recycled, according to them. It only creates more unsustainable waste.	
indicated_trust_of_tech	normalised_trust_in_tech*effect_of_depreciated_panels_on_trust_of_tech		dmnl	This converter represents the indicated trust of the technology. Its unit is dimensionless. It is changed by an effect variable of depreciated solar panels and the normalised trust in technology.	
normalised_trust_in_tech	0,5		dmnl	This represents the normalised trust in tech. The value is set as 0.5.	
Perceived_Risk(t)	Perceived_Risk(t - dt) + (change_in_risk_perception) * dt	INIT Perceived_Risk = 0,9	dmnl	This converter represents the perceived risk. Its unit is dmnl. Many perceive the investment to be too risky because it is expensive and does not believe	NON-NEG

				the panels can perform in Norway.	ATIVE
time_to_adjust_risk_perception	5		years	This parameter represents the time it takes to adjust risk perception. It is assumed long, because non-adopters seem slow to adjust their worldview.	
time_to_adjust_trust_in_tech	5		years	This parameter represents the time it takes to adjust the trust in tech. It is assumed long, because non-adopters seem slow to adjust their worldview.	
Trust_in_Tech(t)	Trust_in_Tech(t - dt) + (change_in_trust_of_tech) * dt	INIT Trust_in_Tech = 0,01	dmnl	This converter represents the trust in technology. Its unit is dimensionless. Many non-adopters does not trust in the technology and is distributive in general about it.	NON-NEGATIVE
Electricity:					
electricity_price	IF TIME < 2022 THEN electricity_price_2015_to_2021 ELSE electricity_price_after_2022		NOK/(kw*hours)	This converter represents the electricity price in NOK/kWh.	
electricity_price_2015_to_2021	GRAPH(TIME) Points: (2015,000, 0,325), (2016,000, 0,385), (2017,000, 0,419), (2018,000, 0,593), (2019,000, 0,595), (2020,000, 0,252), (2021,000, 0,876)		NOK/(kw*hours)	This represents the data of the electricity price from 2015 to 2021. Collected from (Statistisk Sentralbyrå, 2022a).	
electricity_price_after_2022	1,5		NOK/(kw*hours)	This converter represents the electricity price from 2022 and after. Used to test.	
Panels_and_Capacity:					

Accumulated_Installed_Capacity(t)	Accumulated_Installed_Capacity(t - dt) + (change_in_capacity - depreciation_2 - decrease_capacity_per_reuse) * dt	INIT Accumulated_Installed_Capacity = 120	kw	This stock represents the accumulation of newly installed capacity. The unit is kw. The stock is affected by two flows: the new capacity per year and depreciation. New capacity per year increases the stock. while deprecation depletes the stock as panels age (Walker, 2022).	NON-NEGATIVE
Accumulated_Installed_Solar_Panels(t)	Accumulated_Installed_Solar_Panels(t - dt) + (change_in_panels - depreciation - reused_panels) * dt	INIT Accumulated_Installed_Solar_Panels = 1530	panels	This stock represents the accumulated panels installed in Norway. Its unit is panels. It is increased by change in panels and depleted either by reuse or by depreciation.	NON-NEGATIVE
average_capacity_per_adopter	Accumulated_Installed_Capacity/Adopter		kw/household	This converter represents the capacity each adopter has installed. Its unit is kW per person. It is calculated by the cumulative installed capacity and the number of adopters.	
average_kw_adopted_per_household	change_in_capacity//adoption_rate		kw/household	This is a calculation of average kw per household.	
change_in_capacity	(kw_per_panels*change_in_panels)		kw/years	This flow represents the new capacity that is installed per year. Its unit is kw per years. When new panels are installed, there will be an increased cumulative capacity of solar panels.	UNIFLOW
change_in_panels	(panels_per_adopter*adoption_rate)		panels/years	This flow represents the change in panels. The unit is panels per year. Essentially, it is the same flow	UNIFLOW

				as the adoption rate, but as the accumulation of panels.	
decrease_capacity_per_reuse	Accumulated_Installed_Capacity*fraction_reusing	OUTFLOW PRIORITY: 2	kw/years	This outflow represents the decrease of capacity from reusing solar panels. When solar panels are taken out of use, this will decrease the capacity as well, until they are installed again to new adopters.	UNIFLOW
Depreciated_Panels(t)	Depreciated_Panels(t - dt) + (depreciation - recycled_panels) * dt	INIT Depreciated_Panels = 0,001	panels	This stock represents the depreciated solar panels. The unit is panels and assumed initial value to be 0. It is increased by the depreciation flow and decreased by recycled panels if the policy is on.	NON-NEGATIVE
depreciation	Accumulated_Installed_Solar_Panels/time_to_deprecate	OUTFLOW PRIORITY: 1	panels/years	This flow represents the deprecation of the capacity of the solar panels. Its unit is kw per years.	UNIFLOW
depreciation_2	Accumulated_Installed_Capacity/time_to_deprecate	OUTFLOW PRIORITY: 1	kw/years	This flow represents the outflow of accumulated installer capacity as panel depreciate. Its unit is kw per year. This out flow is essentially the same as the depreciation flow from installed panels.	UNIFLOW
fraction_recycling	IF TIME < 2022 THEN 0 ELSE 0,2		dmnl/year	This parameter represents the fraction recycling. Its unit is dmnl/year. The value is explained in the thesis.	
fraction_reusing	IF TIME < 2022 THEN 0 ELSE 0,04		dmnl/year	This parameter is the fraction of all panels that are sold and re-used. Its unit is dmnl per year.	

				The fraction further in the policy chapter.	
kw_per_panels	0,5		kw/panels	This parameter represents the amount of capacity per panel. Its unit is kw per panel. Typically, panels are measured in watts and per observations in interest groups, they seem to be 200-400 watt per panels.	
material_recovery_rate	0,95		dmnl	This converter represents how much of the recycled material can be recovered. The value is set to 0.95 per literature (World Economic Forum, 2022).	
panels_per_adopter	16		panels/household	This parameter represents the number of panels an adopter buys. Its unit is panel per household. Generally, the typical adopter buys between 16 and 20 panels, although with some buying significantly more (60 has been observed in online groups). No average number of panels were found, so it was calibrated to around 30.	
recycled_panels	DELAY3(material_recovery_rate*(Depreciated_Panels*fraction_recycling); time_of_recycling_process)*switch_2		panels/year	This flow represents the recycled panels policy. Its unit is panels per year.	UNIFLOW
reused_panels	(Accumulated_Installed_Solar_Panels*fraction_reusing)*switch_3	OUTFLOW PRIORITY: 2	panels/year	This flow represents the policy reusing panels. Its unit is panels per year. The policy attempts to increase the inventory of solar panels and adopters in Norway.	UNIFLOW
switch_2	0		dmnl	policy switch	
switch_3	0		dmnl	policy switch	
time_of_recycling_process	2		years	This parameter represents the time it takes to recycle solar	

				panels. Assumed to take a while, set to 2 years.	
time_to_depr ecate	30		Years	This parameter represents the time it takes to deprecate. Its unit is years. Panels are generally reported to last between 25-40 years. The value in the model simulation set to 30.	
total_househ olds	Adopter+Potential_A dopter+Non_Adopter		house hold	This converter represents the total population and is equal to the additive of non-adopters, potential adopters and adopters.	
PV_supplier:					
Accumulated _Panels_Prod uced(t)	Accumulated_Panels _Produced(t - dt) + (inflow_accumulation _production) * dt	INIT Accumula ted_Panel s_Produce d = 1000	panel s	This stock represents the accumulated panels produced and its unit is panels. The stock is needed to exemplify how more panels increases the new experience of production them.	NON-NEGATIVE
Backlog_of_ Received_Or ders(t)	Backlog_of_Receive d_Orders(t - dt) + (Receiving_Orders - orders_ready_to_fulfi l) * dt	INIT Backlog_ of_Receiv ed_Orders = initial_bac klog_of_r eceived_o rders	house hold	This stock represents the backlog of received orders. If the suppliers cannot take the offer, it accumulates here. Its unit is household.	NON-NEGATIVE
Cumulative_ Production_E xperience(t)	Cumulative_Producti on_Experience(t - dt) + (production_experien ce) * dt	INIT Cumulativ e_Product ion_Exper ience = 0,5	dmnl	This stock represents the cumulative production experience. Its unit is dimensionless. It is affected by the flow of new production experience. The structure is based on Sterman's model on economy of scales.	NON-NEGATIVE

demand_of_PV	(Potential_Adopter*fraction_becoming_willing_to_adopt_PV)/time_to_adjust_norms		household/years	This converter represents the demand of solar panels. Its unit is household per years. It is calculated similarly to how the adoption rate except for the constraint. This is, in other words, it is the real demand of how many wants to adopt solar panels.	
desired_shipment_to_inventory	Receiving_Orders*panels_per_adopter		panels/years	This converter represents the desired shipment of panels to the inventory. Its unit is panels per year. Desired shipment inventory is simplified structure from Sterman's Beer Model. It assumes the supplier will order the same volume of panels as received in orders with no further coverage of panels as may be more common for ordering.	
effect_of_all_panels_produced_on_production_experience	GRAPH(Accumulated_Panels_Produced/INIT(Accumulated_Panels_Produced)) Points: (0,000, 0,000), (0,200, 0,200), (0,400, 0,400), (0,600, 0,600), (0,800, 0,800), (1,000, 1,000), (1,200, 1,200), (1,400, 1,400), (1,600, 1,600), (1,800, 1,800), (2,000, 2,000)		dmnl	This graphical function represents the effect of all panels produced on experience. Its unit is dimensionless. The equation illustrates how producers of panels and any R&D on panels leads to more experience.	
effect_of_experience_on_cost	GRAPH((Cumulative_Production_Experience/INIT(Cumulative_Production_Experience))^learning_curve_strength) Points: (0,000, 2,000), (0,200, 1,975), (0,400, 1,913),		dmnl	This graphical variable represents the effect of experience on the price of the technology. Its unit is dimensionless. With more experience and R&D, the price of technology decreases.	

	(0,600, 1,767), (0,800, 1,465), (1,000, 1,000), (1,200, 0,5352), (1,400, 0,2331), (1,600, 0,08682), (1,800, 0,02526), (2,000, 0,000)				
effect_of_fulfilled_orders_on_supplier_instalment_knowledge	GRAPH(Fullfilled_Orders/INIT(Fullfilled_Orders)) Points: (0,000, 0,000), (0,200, 0,200), (0,400, 0,400), (0,600, 0,600), (0,800, 0,800), (1,000, 1,000), (1,200, 1,200), (1,400, 1,400), (1,600, 1,600), (1,800, 1,800), (2,000, 2,000)		dmnl	This graphical function affects the instalment knowledge by new fulfilled orders. Its unit is dimensionless. It starts normalised at 1. If more orders are fulfilled, they experience more knowledge which affects the accumulated knowledge. It is assumed to not decrease below 1 as they do not lose knowledge.	
effect_of_instalment_knowledge_on_price_of_installation	GRAPH((Instalment_Knowledge/INIT(Instalment_Knowledge))^learning_curve_strengt_installation) Points: (0,000, 2,000), (0,200, 1,975), (0,400, 1,913), (0,600, 1,767), (0,800, 1,465), (1,000, 1,000), (1,200, 0,664), (1,400, 0,597), (1,600, 0,559), (1,800, 0,521), (2,000, 0,521)		dmnl	This graphical function represents the effect of knowledge on price of installation. Costs decreases because of learning (Nemet *et al.*, 2020).	
effect_of_material_scarcity_on_price	GRAPH((Producer_Inventory/INIT(Producer_Inventory))^elasticity_of_material_on_price) Points: (0,000, 2,000), (0,200, 1,975), (0,400, 1,913), (0,600, 1,767), (0,800, 1,465),		dmnl	This graphical function represents the effect of material of scarcity on price. Its unit is dimensionless. When panels (and materials) are scare prices of the panels should increase, while when the opposite is true, prices decrease.	

	(1,000, 1,000), (1,200, 0,5352), (1,400, 0,218), (1,600, 0,114), (1,800, 0,076), (2,000, 0,076)				
elasticity_of_material_on_price	0,045		dmnl	This parameter represents the elasticity of material on price. Its unit is dmnl.	
fulfilling_orders	MIN(demand_of_PV; installation_capacity)		household/years	This flow is the flow orders fulfilled per years. Its unit is household per year. It represents how many orders can be fulfilled each year for a household adopter. The equation is a MIN-function where the backlog of received orders is fulfilled by the minimum of backlog divided by the waiting time or by the converter adopter helped constrained.	UNIFLOW
Fullfilled_Orders(t)	Fullfilled_Orders(t - dt) + (fulfilling_orders) * dt	INIT Fullfilled_Orders = 200	household	This stock represents the fulfilled orders based on any constraints there might be in the system. Its unit is household. The stock is increased by the fulfilling orders flow. The initial number is equal to the adopter initial of 200.	NON-NEGATIVE
indicated_production_experience	normalised_production_experience*effect_of_all_panels_produced_on_production_experience		dmnl	This converter represents the indicated production experience. Its unit is dimensionless. The indicated production experience is how much is being learnt.	
inflow_accumulation_production	production_rate		panels/years	This flow represents the accumulation of panels and "counts" how many panels	UNIFL

				have been produced. Its unit is panels per year.	OW
initial_backlog_of_received_orders	1		household	Initial backlog of received orders. Assumed to be at 0.	
initial_installation_price	50000		NOK/household	This parameter represents the price of installation of the panels. Its unit is NOK/household.	
initial_price_of_technology	60000		NOK/household	This parameter represents the initial price of the technology. Its unit is NOK per household.	
initial_producer_panels_available_for_shipment	60000		panels	Initial producer panels available for shipment. Tested in thesis.	
initial_supplier_inventory	10000		panels	Initial supplier inventory. Tested in thesis.	
installation_capacity	maximum_panels_installed/panels_per_adopter		household/years	This converter represents how many adopters are helped with their need for panels. Its unit is household per year. The equation calculates how many adopters can have their panels installed every year.	
learning_curve_strengt_installation	0,03		dmnl	This parameter represents the learning curve strength from instalment knowledge. With more knowledge of instalment, the price decreases as installers become more efficient (Nemet *et al.*, 2020).	
learning_curve_strength	0,124		dmnl	This parameter represents the strength of the learning curve on the effect. Its unit is dimensionless. The parameter is an elasticity that says when the increase of experience relative to the initial experience rises, the effect increases to the power of the number of the elasticity.	

				This value is unknown and will be tested.	
material_available	5000		panels	This parameter represents the material available. Its unit is panels.	
maximum_panels_installed	MIN(maximum_panels_installed_per_year; Supplier_Inventory/time_to_ship_to_adopter)		panels/years	This converter represents the maximum panels installed. The unit is panels per year. The idea of the converter is to model a constraint in the market where how many fulfilled orders of panels are limited by how many available panels there are and how many are available to install the panels. The equation is a MIN-function to illustrate the limit. If the supply is low, then installers cannot install more than how many panels are available. If there are few installers, then the installers become the limit, where panels stay in the inventory as they cannot be installed.	
maximum_panels_installed_per_installer_per_year	400		panels/installers/year	This parameter is the maximum panels installed per installer per year. Its unit is panels per installer per year. The value is set to 1000, but in the simulation, it will not react beyond 400 due to constraints in the supplier inventory.	
maximum_panels_installed_per_year	Installers_Available*maximum_panels_installed_per_installer_per_year		panels/Years	This converter represents the maximum panels installed by installers per year. The equation calculates how many panels can at most be installed by the available installers and their productivity per year.	

normalised_production_experience	0,5		dmnl	This parameter represents the normalized production experience. Its unit is dimensionless.	
orders_ready_to_fulfil	IF demand_of_PV < installation_capacity THEN 0 ELSE installation_capacity		household/years	This flow represents the orders ready to be fulfilled. Its unit is household per year. To avoid an outflow when the capacity is higher than the demand, there is an IF THEN function. The idea is if it can be supplier, it will not be accumulated in the backlog in the first place.	UNIFLOW
price_of_installation	initial_installation_price*effect_of_instalment_knowledge_on_price_of_installation		NOK/household	This converter represents the price of installation. Its unit is NOK per household. The price is not static and will decrease as more experience and knowledge causes the installations to become more effective per literature.	
price_of_technology	initial_price_of_technology*effect_of_experience_on_cost*effect_of_material_scarcity_on_price		NOK/household	This converter represents the price of the technology. The unit is NOK per household. It is inspired by an assignment (Sterman, 2013)	
Producer_Inventory(t)	Producer_Inventory(t - dt) + (production_rate - shipment_rate_from_producer) * dt	INIT Producer_Inventory = initial_producer_panels_available_for_shipment	panels	This stock represents the panels that are (essentially) available for the Norwegian Market. Its unit is panels. The stock is increased by the production of new panels and depleted by the shipment to the inventory in Norway.	NON-NEGATIVE
production_experience	(indicated_production_experience-Cumulative_Production_Experience)/time_to_adjust_production_expereience		dmnl/year	This flow represents the inflow of new experience from production of solar panels.	

production_rate	production_rate_options+recycled_panels		panels/Years	This flow represents the production rate of solar panels. Its unit is panels per years. The equation is the additive of the produced panels and recycled panels.	UNIFLOW
production_rate_options	material_available/time_to_build*(1-switch_1) + desired_shipment_to_inventory*switch_1		panels/year	This converter represents the production rate options. There are two scenarios: one ideal production rate, which produces as much solar panels as is desired by the suppliers, and a production rate that slowly decreases due to depletion of resources or other shocks currently experienced.	
Receiving_Orders	IF demand_of_PV < installation_capacity THEN 0 ELSE DELAY(demand_of_PV; time_to_perceive_orders)		household/Years	This flow represents the flow of orders from the demand. The unit is household per year. The flow is affected by the demand and how long it takes the supplier of solar panels to perceive new orders. As they the orders are perceived, the accumulate in the backlog of received orders.	UNIFLOW
shipment_rate_from_inventory	fulfilling_orders*panels_per_adopter		panels/Years	This flow represents the shipment rate from the inventory. The unit is panels per year. The outflow ensures the inventory decreases with shipment.	UNIFLOW
shipment_rate_from_producer	MIN(Producer_Inventory/time_to_ship_from_producer; DELAY(desired_shipment_to_inventory; time_to_ship_from_producer))		panels/years	This flow represents the external shipment of panels from the producer of panels. Its unit is panels per year. The equation is a MIN-function where the ideal shipment to inventory is the desired shipment from orders. It could, however, be constrained by how many	UNIFLOW

				available panels from the producer. E.g., when there are problems with the supply line (lack of minerals, war etc.), the total inventory in Norway would deplete as the supplier are installing panels, but not receiving panels from the producer. (This one flow combined with the previous stock and flow is simplified and for testing of the effect on the demand-side of the model. The many minerals found in panels will most likely be a model in itself, thus the time-parameters are an average exemplifying how long it could possibly take. Sensitivity testing of the parameters have been conducted for more information of the effect of these variables).	
shipment_reused_panels	DELAY(reused_panels; time_to_ship_reused_panels)		panels/year	This flow represents the new solar panels accumulating. The unit is panels per year.	UNIFLOW
Supplier_Inventory(t)	Supplier_Inventory(t - dt) + (shipment_rate_from_producer + shipment_reused_panels - shipment_rate_from_inventory) * dt	INIT Supplier_Inventory = initial_supplier_inventory	panels	This stock represents the inventory of the suppliers. Its unit is panels. The stock is increased by the shipment of panels from the producer and depleted by the shipment rate from inventory.	NON-NEGATIVE
switch_1	0		dmnl	This is a policy switch.	
time_to_adjust_production_expereience	1		years	This parameter represents the time it takes to adjusting production experience. Its unit is years.	
time_to_build	3/12		Years	This parameter represents the time it takes to build.	

time_to_perceive_orders	1/48		years	This parameter represents the time it takes to perceive orders. Its unit is years.	
time_to_ship_from_producer	0,5		years	This parameter represents the time it takes to ship panels to the supplier from the producer. Its unit is years.	
time_to_ship_reused_panels	0,5		years	This parameter represents the time it takes to ship reused panels. Its unit is years. The value is unknown but is set to 0.5 years from the time an adopter sells panels to it is eventually prepared to be re-installed.	
time_to_ship_to_adopter	0,5		years	This parameter represents the time to ship the panels to the adopter. Its unit is years.	
total_price_of_PV_technology	(price_of_installation+price_of_technology)		NOK/household	This converter represents the total price of buying solar panels. Its unit is NOK per household. The equation is the additive of the price of installation and the price of the technology. The price is calculated from (Solcellespesialisten, 2021) who states they cost between 40 000 NOK to 150 000 NOK. The total price is assumed to be 174 000 NOK in the beginning.	
Supplier_Instalment:					
change_in_installers	Installers_Available*growth_installers		installers/years	This flow represents the change in installers and is changed by a growth of installer by hiring.	UNIFLOW
change_in_instalment_knowledge	(indicated_installment_knowledge-Instalment_Knowled		dmnl/year	This flow represents the change in instalment knowledge. Its unit is dimensionless per year.	

	ge)/time_to_adjust_instalment_knowledge				
growth_installers	IF TIME < 2022 THEN hiring_fraction*pressure_to_hire ELSE policy:_hiring_fraction*(switch_4) + hiring_fraction*pressure_to_hire*(1-switch_4)		dmnl/year	This converter represents the growth of installers.	
hiring_fraction	0,03		dmnl/year	This parameter represents the normal hiring fraction before a policy is implemented.	
indicated_installment_knowledge	normalised_instalment_knowledge*effect_of_fulfilled_orders_on_supplier_instalment_knowledge		dmnl	This converter represents the indicated instalment knowledge and is affected by how many fulfilled orders there are. This assumes that with more fulfilled order, the more knowledge they have accumulated.	
initial_installers_available	200		installers	Initial installers available. Tested in thesis.	
Installers_Available(t)	Installers_Available(t - dt) + (change_in_installers - quiting_and_retirement) * dt	INIT Installers_Available = initial_installers_available	installers	This stock represents the available installers. Its unit is installers.	NON-NEGATIVE
Instalment_Knowledge(t)	Instalment_Knowledge(t - dt) + (change_in_instalment_knowledge) * dt	INIT Instalment_Knowledge = 0,5	dmnl	This represents the instalment knowledge. Its unit is dimensionless. It is the lack of knowledge of instalment that affects the dissatisfaction (Karjalainen and Ahvenniemi, 2019).	NON-NEGATIVE

normalised_instalment_knowledge	0,5		dmnl	This parameter represents the normalised instalment knowledge. It is set to 0.5.	
policy:_hiring_fraction	0,07		dmnl/year	This parameter represents the hiring fraction in the policy. The value has been tested with several different growth rates but is 0.07 in the policy scenario.	
pressure_to_hire	GRAPH(demand_of_PV//INIT(demand_of_PV)) Points: (0,000, 0,000), (0,200, 0,02526), (0,400, 0,08682), (0,600, 0,2331), (0,800, 0,5352), (1,000, 1,000), (1,200, 1,465), (1,400, 1,767), (1,600, 1,913), (1,800, 1,975), (2,000, 2,000)		dmnl	This graphical function is affected by the demand and increases the growth of installers, assuming more demand means more installers hired.	
quiting_and_retirement	Installers_Available/time_before_ending_employment		installers/years	This flow represents installers quitting or retiring.	UNIFLOW
switch_4	0		dmnl	This is a policy switch	
time_before_ending_employment	40		years	This parameter represents the time it takes to end employment. It is set to 40 years from being an educated installer to retiring.	
time_to_adjust_instalment_knowledge	5		years	This parameter represents the time it takes to adjust instalment knowledge.	

Run Specs	
Start Time	2015
Stop Time	2050
DT	1/52
Fractional DT	True

Save Interval	0,0192307692308
Sim Duration	0
Time Units	years
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000

Custom Unit	Aliases	Equation
Dimensionless	dmnl unitless	1
kilowatt hours per day		kWh/day
kilowatts	kilowatt	kW

APPENDIX D: Sensitivity Analysis

Appendix D adds the variables that were sensitive to parameters, but not included in the summary in chapter 5. Any variable that revealed little sensitivity has been excluded except for the drivers, because this is interesting for the policy decisions.

D.1 Parameters

Parameter and Type of Sensitivity Test	Time to Adjust Norms Uniform, Sobol, 0,001-5

The adopter populations are sensitive to the time to adjust norms and the behaviour seems to either grow or fail, as seen in figure D.1 with adopters. This can also be seen in the other adopter populations in figures D.2 and D.3. The time it takes to change norms is therefore important for the growth of adopters.

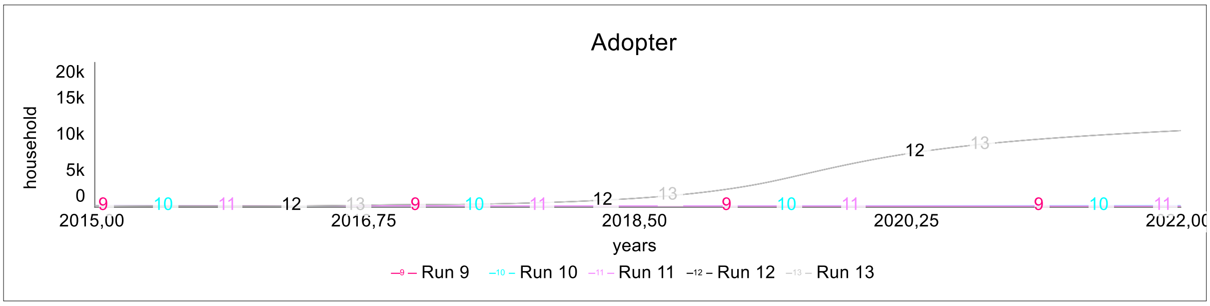


Figure D.1 – Sensitivity test, time to Adjust Norms effect on Adopter.

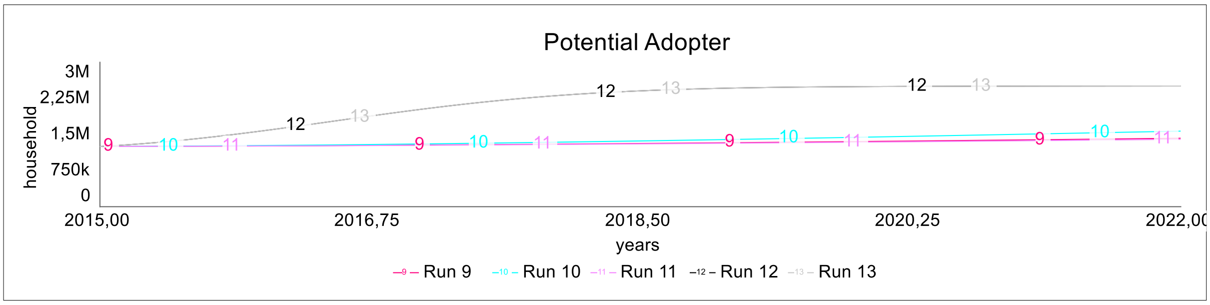


Figure D.2 – Sensitivity test, time to adjust norms effect on non-adopter.

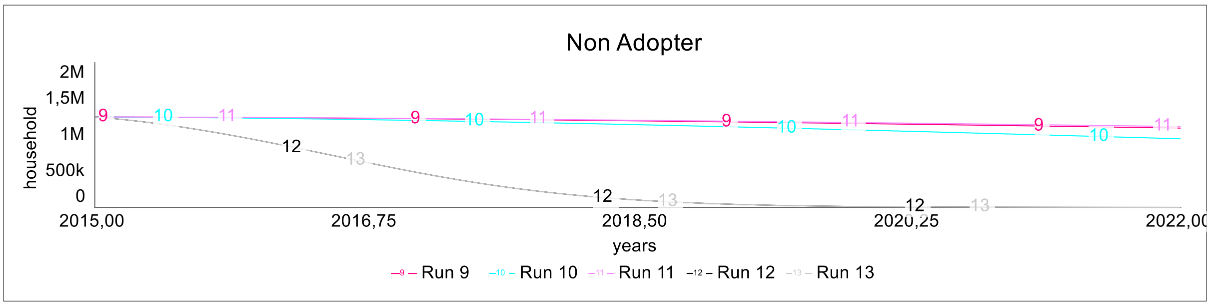


Figure D.3 – Sensitivity test, time to adjust norms effect on potential adopter.

Parameter and Type of Sensitivity Test	Time to Adjust Motivation Uniform, Sobol, 0-10

The sensitivity analysis shows that varying between 0 to 10 years to adjust motivation will affect the motivation for self-sufficiency, but not how much is adopted (apart from the time between 2015 and 2022). This is illustrated in figure D.4 and D.5 below.

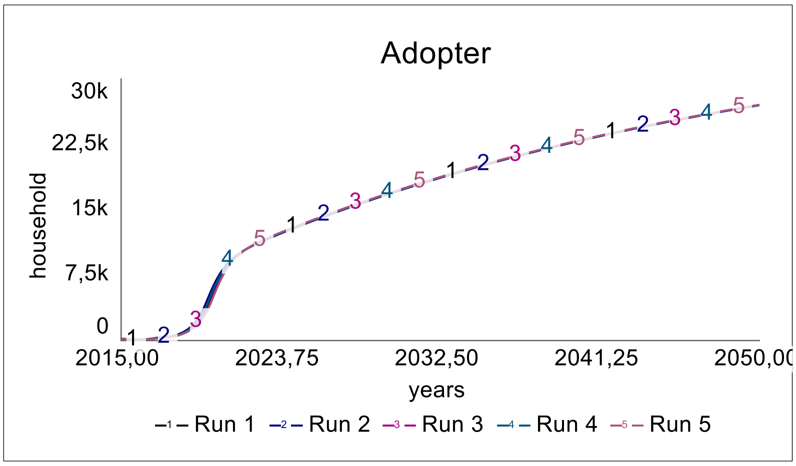


Figure D.4 – Sensitivity test, time to adjust motivation on adopters.

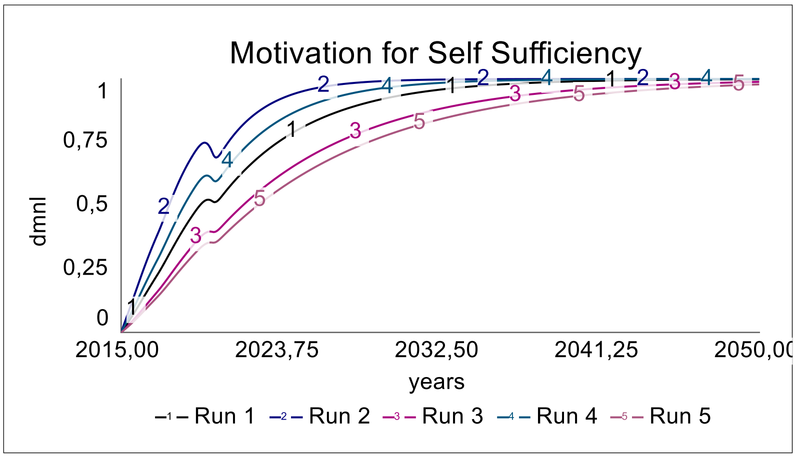


Figure D.5 – Sensitivity test, time variable effect on motivation for self-sufficiency.

This pattern can also be seen in the other stock-variables, if changing the time-variables between 0-10 years.

Parameter and Type of Sensitivity Test	Time to change perceived environmental performance

	Uniform, Sobol, 0-10

Like previous sensitivity tests are there little changes to adopters, only changes to the timing of the *perceived environmental performance*. This can be seen in figure D.6 and D.7 below.

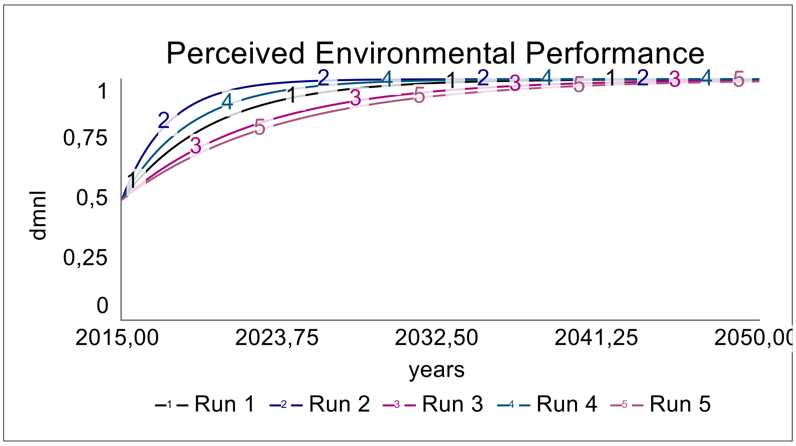


Figure D.6 – Sensitivity test, time to change perceived environmental performance on perceived environmental performance.

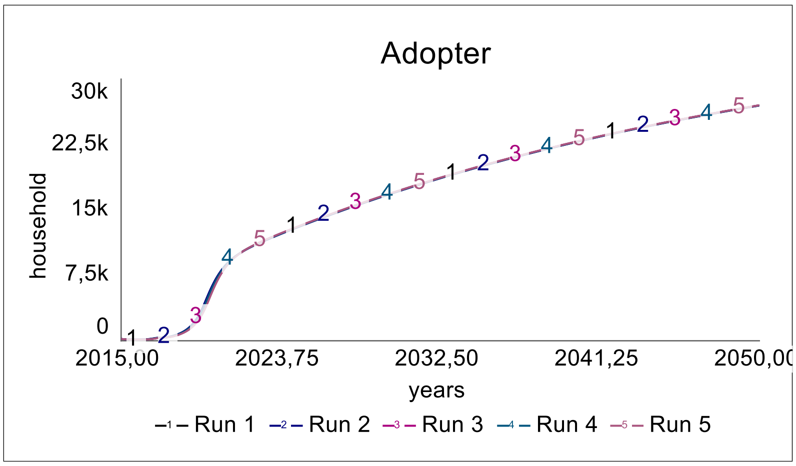


Figure D.7 – Sensitivity test, time to change perceived environmental performance effect on adopters.

Parameter and Type of Sensitivity Test	Time to perceive performance Uniform, Sobol, 0-10

While *knowledge of performance of PV* is sensitive to changes to *time to perceive performance*, it does not affect adopter. This can be seen in D.8 and D.9

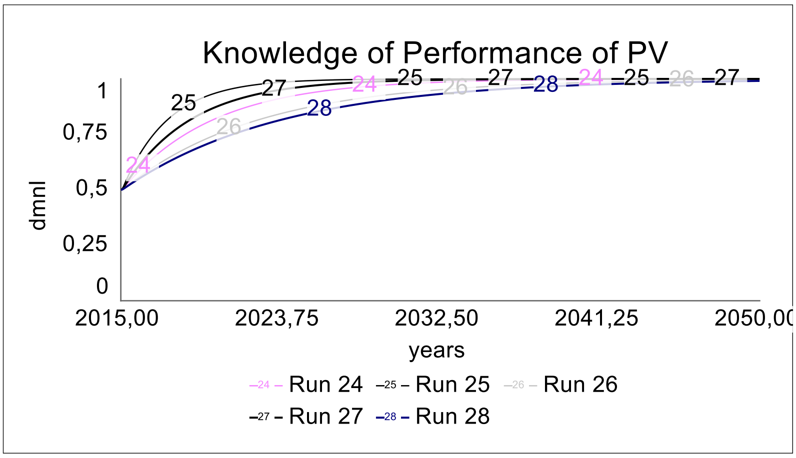


Figure D.8 – Sensitivity test, time to adjust performance on knowledge of performance.

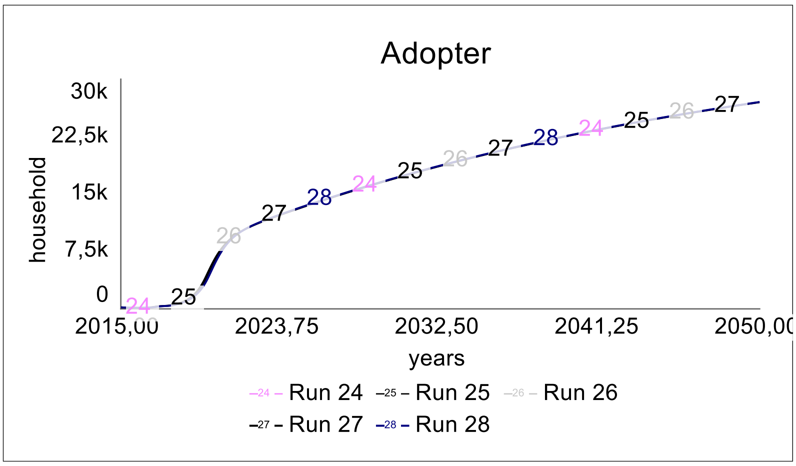


Figure D.9 – Sensitivity test, time to adjust performance on adopters.

D.2 Graphical Tables

There are none to minimal changes in behaviour from sensitivity tests on graphical function. The tests were conducted by changing between linear effect to S-shaped effect, normalised at time 0 (1,1).

Effect of scarcity on price minimally affected price, however, did not change any behaviour on the adopter population. For the drivers of diffusion, only *motivation for self-sufficiency* were affected by the effect-variable *effect of energy cost on motivation for self-sufficiency*. This also minimally.

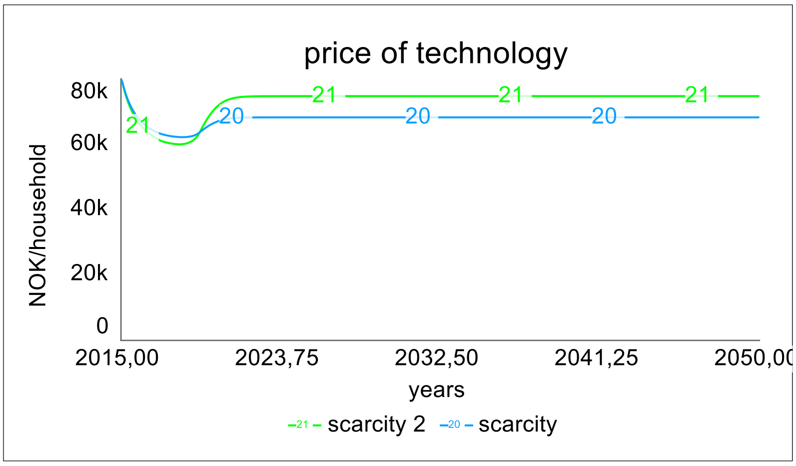


Figure D.10 – graphical sensitivity test, scarcity on price of technology.

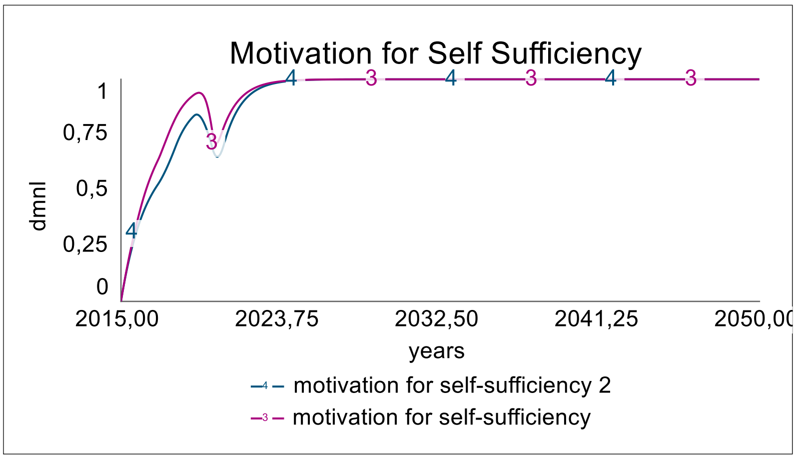


Figure D.11– graphical sensitivity test, energy cost on motivation for self-sufficiency.

APPENDIX E: Observation Coding and notes

Observed	Source	Notes/comment	Included
Distrust	Facebook comment section	Several (non-adopter) commenting. “Idiocy”, “rubbish” by one person, also comments on panels being plastic-y waste.	Yes. Distrust from depreciated solar panels.
Distrust	Facebook comment section	Ruining visibility of neighbourhood.	Yes, but not as effect of visibility.

Distrust	Facebook comment section	This "rubbish" about solar panels (and wind) makes us forget about nuclear power and hydro.	Yes, distrust.
Knowledge of performance	Facebook comment section	(Non-adopter) Asks questions about latitude effect on performance and winter – not willing to consider answer.	Yes. Knowledge of performance from energy produced.
Knowledge of performance/distrust	Facebook comment section	"Does it work in the winter with snow on top?", "does it work in night?".	Yes.
Knowledge of performance	Facebook comment section.	Snow on roof affecting performance/use. Non-adopter not listening to answer.	Yes.
(High) Cost of solar panels.	Facebook comment section.	(Article on about benefits in banks from solar panels). Several comments like: "What about investment cost?"	Yes.
(High) Cost of solar panels.	Facebook comment section.	Relatively positive to the technology, but comments on too high investment cost.	Yes.
Environmental	Facebook comment section.	(Article about bureaucracy declining solar panels) Shows many consider it as	Yes, environmental performance.

		environmentally friendly source of energy.	
Knowledge of performance	Facebook comment section.	Non-adopter finding it useless.	Yes – affecting perceived risk.
Distrust or risk/knowledge of performance	Facebook comment section.	Does not believe the adopter makes the money they claim.	Yes, both distrust/risk and knowledge.
Knowledge of performance	Facebook comment section.	Never useful in Norway with long, dark winter.	Yes.
Knowledge of performance	Facebook comment section.	Winters mentioned and consumer patters (referring to using most electricity in the winter).	Yes.
Installation cost + cost of technology	Twitter	Answer to post commenting that the high cost is not necessarily the solar panels, but installation.	Yes. Disintegrated price of investment of installation and technology.
Seeking knowledge	Twitter	Potential adopter asking questions about performance and cost.	Yes. Knowledge of performance affecting perceived performance which affects risk.

Table D.1 – Notes on comment section.