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Prosumers role in a changing electricity system: the non-individual prosumer perspective

Master's thesis in Systems, Control and Mechatronics

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Department of Earth, Space and Technology
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2020

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Abstract

The transition into a clean energy market is opening up new possibilities for traditional electricity consumers. The conventional centralized production structure is shifting towards a distributed one, with micro-producers acquiring a decisive role as active stakeholders in the system, consuming and producing renewable electricity. In Sweden, these so-called prosumers, are mostly represented by non-individual organisations. Understanding the motives that encourage them to install solar PV panels and the barriers encountered in the process, is needed to provide solutions that will be able to cope with a significant penetration of renewable electricity levels into the energy mix.

This project strives to cover this gap by deploying a systems approach to build two models based on a System Dynamics (SD) method, where the factors affecting non-individual adopters of PV panels in the decision-making process, and the underlying complexities and interrelations inherent to it are uncovered. To build up the model, an iterative process has been followed, based on a mixed-methods approach, used to filter and sort out the information extracted from a set of interviews conducted with prosumer organisations. In turn, these findings have contributed to the definition of the variables and the causal loop relationships that govern the Causal Loop Diagram and Stock and Flow Diagram.

It has been revealed that prosumer organisations are driven by cost reductions as the main goal to adopt prosumerism, with environmental motives, customer satisfaction, diversification or access to a RES as other key factors for investing in solar PV electricity.

Keywords: Solar PV, Motives, Barriers, System Dynamics, Sweden

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To all my people back home, thank you so much for being so amazing.

Carlos Canelada, Gothenburg, May 2020

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Nomenclature

List of Acronyms

BRF	Bostadsrättsförening
BSS	Battery Storage System
CLD	Causal Loop Diagram
DSM	Demand Side Management
DSO	Distributed System Operator
FiT	Feed-in Tariff
GHG	Green House Gases
IPP	Independent Power Producer
LCOE	Levelized Cost of Electricity
PPA	Power Purchase Agreement
PV	Photovoltaics
RES	Renewable Energy Source
RET	Renewable Energy Technology
SD	System Dynamics
SFD	Stock and Flow Diagram
SoC	State of Charge
TSI	Technological System

List of Unit Abbreviations

kWh	Kilowatt-hour
kWp	Kilowatt-peak
MWh	Megawatt-hour
MWh	Megawatt-peak

1 Introduction

1.1 Background

In the last couple of decades, the energy market in Sweden has undergone a transition spurred by the will to achieve cleaner ways of producing electricity and ensuring the sustainability of the future energy system. The rise in power demand, together with the scarcity of conventional fossil fuels has transformed the energy sector significantly and called for long-term sustainable solutions.

In the late 90s, nuclear power had established itself as the main electricity provider in Sweden [Cruciani, 2016]. Meanwhile, petroleum-derived electricity started to experience a depletion in favour of alternative electricity solutions such as bioenergy, induced by the higher taxation on GHG emissions and the larger state-granted financial aids. After the crisis that hit the country between 1991 and 1993 new energy policies were introduced, including a newly developed system of green certificates, which prompted the use of Renewable Energy Sources (RES) [Cruciani, 2016].

The production of clean electricity is, among other factors, dependent on the geological and weather conditions of a country. For Sweden, the hydro resources present in the north make the country suitable for hydroelectricity generation. As a matter of fact, hydro is nowadays the predominant source of electricity production [Lindahl et al., 2018].

Solar energy, on the other hand, has often been disregarded as a marginal technology in Sweden [Sommerfeldt et al., 2016]. Dark and long winters have led people into believing that Scandinavian countries are less suited for solar power production than their southern neighbours like Germany or Austria, with significantly higher levels of solar PV penetration in their energy mix [Widén, 2010]. This belief is based on the fact that radiation levels in Scandinavian countries are lower and more irregular than in other Northern European countries. In words of [Widén, 2010], "the main challenge at high latitudes is the more pronounced annual variations with long days during summer and short days with a low solar altitude during winter". For this reason, having a regular supply from solar power throughout the year is practically impossible.

Nevertheless, this situation does not necessarily mean that solar energy cannot play a key role in the transition into a fossil-free energy market. As a matter of fact, solar PV technologies have been growing considerably in Nordic countries [Sommerfeldt et al., 2016]. In Sweden, since 2006 solar PV technology has increased its share significantly, prompted by several factors. Cheaper PV panels prices, lower installation costs, and larger economic incentives provided by the government have created an attractive prospect for potential adopters [Lindahl et al., 2018, Palm, 2018].

Only in the period going from 2010 to 2014 the share of solar power increased by 100% [Sommerfeldt et al., 2016]. By the end of 2015, the total capacity of grid-connected solar power was of 50 MW [Sommerfeldt et al., 2016]. From 2015 to 2018, solar PV installations have kept glowing, reaching a peak installed capacity of approximately 411 MW of grid connected systems in 2018, accounting for a market growth of 87% with respect to the previous year [Lindahl et al., 2018].

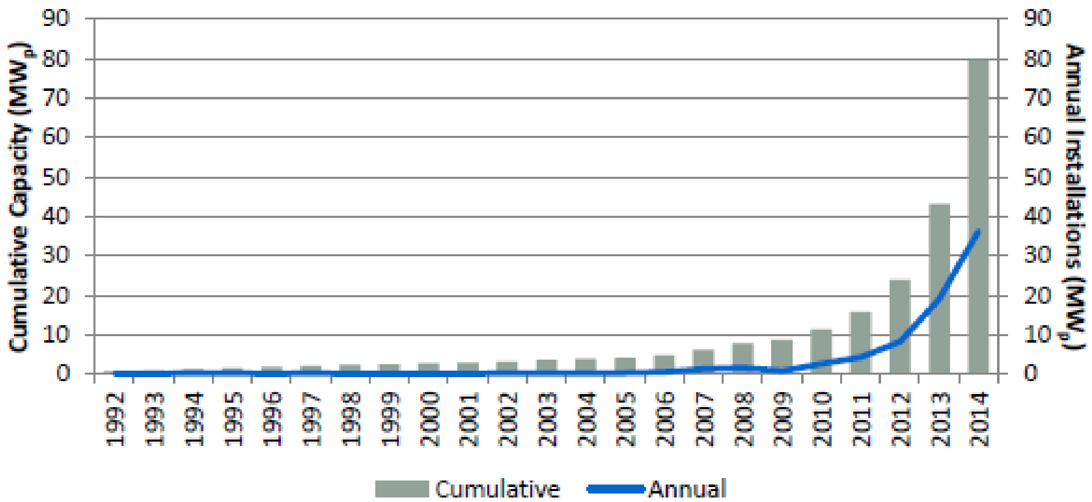

Figure 1.1: Annual and cumulative capacity of solar PV in Sweden [Sommerfeldt et al., 2016]

Regardless of this exponential growth, solar electricity still only accounts for 0.2% of the total electricity production in Sweden [Lindahl et al., 2018], remaining a niche technology [Warneryd and Karltorp, 2020].

Being the share of solar power so small in the country with respect to other technologies, it is logical to ask ourselves why this technology is so important for the future. The answer to this lies on its potential to transform the energy market completely. Small micro-producers can have a high impact on the way the energy is produced, distributed and consumed by inducing the formation of decentralized ownership structures.

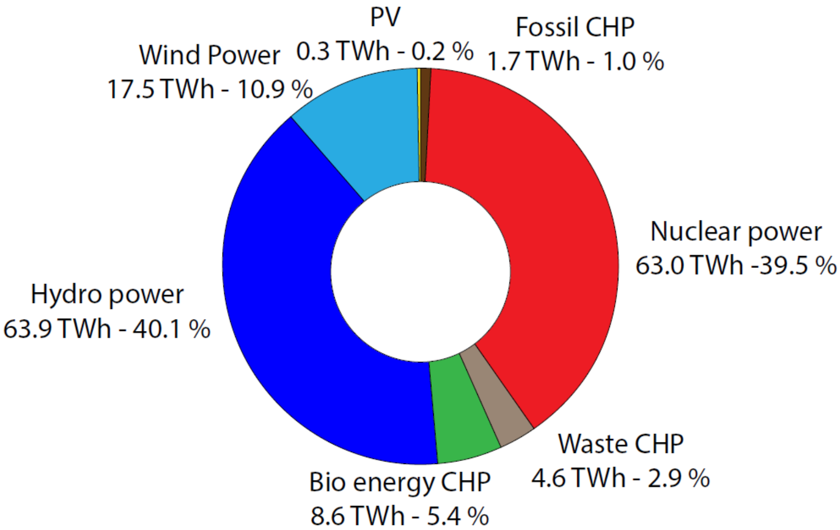

Figure 1.2: Share of produced electricity in Sweden for each type of technology [Lindahl et al., 2018]

At the same time, the enrollment of new actors into the energy scheme is likely to induce changes in the near future [Warneryd and Karltorp, 2020]. Traditional grid consumers, be it persons or companies, who install solar panels on their houses or buildings roofs are encouraged to set aside their conventional passive role as mere system users and become active stakeholders of the electricity system with new roles and responsibilities [Warneryd and Karltorp, 2020]. By doing so, they will fully engage into the process of producing, consuming and trading electricity. They will transit from classic consumers into prosumers.

A prosumer is, by definition, an individual or legal person who produces and consumes electricity in their building. Prosumers are generally reliant on the grid, but they become active users, with the ability to take influencing decisions in their electricity system. Prosumers are a diverse group, from individual households to Real Estate companies, electricity companies or Housing Cooperatives such as the Swedish Tenant-Owned Associations or *Bostadsrättsförening* (BRFs).

In Sweden, most of the installations are conducted in buildings, meaning that prosumers are usually companies [Sommerfeldt et al., 2016]. In most cases, these prosumers are not experts in the electricity market. Therefore, to move past early adoption and reach broader diffusion, it is important that they are educated about the opportunities and risks that come with investment [Sommerfeldt et al., 2016].

Each type of prosumer has their own motivations and expectations from installing the solar PV panels. The financial benefits from producing their own electricity are the primary motives for most types of prosumers [Sommerfeldt et al., 2016]. By installing the panels prosumers are spared from paying the retail price that otherwise, they would be paying, including taxes, grid fees and retailer markups [Sommerfeldt et al., 2016]. On top of this, in the case of households, they are entitled to obtain an economic revenue.

This gives prosumers the ability to speculate in the energy market, as they can decide whether to consume or sell the electricity. The compensation they receive for the fed-back electricity depends on the type of prosumer, but it is a compound of the Nord Pool spot price plus variable tax benefits, grid compensations and tradable green electricity certificates. In addition, applications for subsidies of 20% of the installation are possible in Sweden [Lindahl et al., 2018]. Furthermore, in some countries feed-in tariffs are offered. As it is the case for Sweden, the latter is not so common. Instead, the tax credit system can be accounted for as a feed-in premium policy were a 0.60 SEK/kWh compensation (with a cap of 30000 kWh/year) is granted on behalf of the retailer utility company under the condition of purchasing a higher amount than what its sold back to the grid [Lindahl et al., 2018, Sommerfeldt et al., 2016].

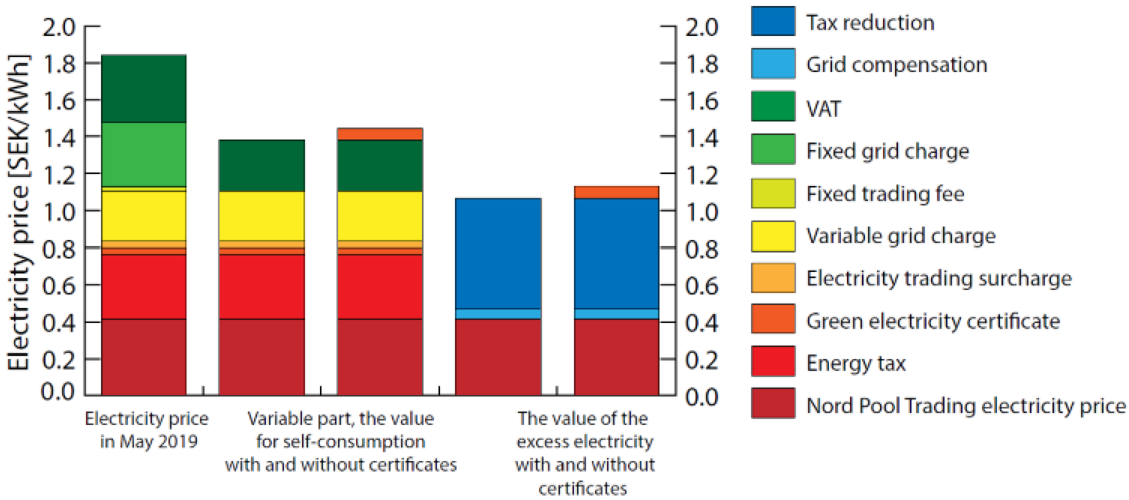

Figure 1.3: Components of the electricity price for Swedish households in 2018 [Lindahl et al., 2018]

As aforementioned, economical incentives are the main drivers for solar PV adoption, but they are not the only decisive factors. Motives to adopt solar PV differ on the type and role of the prosumer [Warneryd and Karltorp, 2020]. During the years 2008-2016, [Palm, 2018] found that in most cases, environmental concerns, security of supply, self-sufficiency, branding motives and increased convenience were key for tilting the balance in favour of embracing solar PV energy.

On the contrary, certain barriers are still preventing its development. High investment costs, lack of a supportive legislation or weak interconnections between the different actors responsible for making the system work, have been revealed as active barriers for PV deployment [Palm, 2018].

Energy companies and retailers can facilitate to overcome these barriers. According to [Amelin, 2015], the electricity generation business is characterized by the presence of numerous economies of scale, leading to the very few but powerful producer companies. To establish a connection between these large companies and the prosumers, the figure of the retailer is fundamental, acting as an intermediate who purchases the electricity from producers and sells it to consumers. They are responsible for generating competence among producers and provide services like risk taking or ensuring price stability [Amelin, 2015]. Retailers in Sweden have the possibility to arrange the contracts independently, as the market is deregulated [Sommerfeldt et al., 2016]. The most common agreement between consumers and retailers is the Floating Price contract [Sommerfeldt et al., 2016].

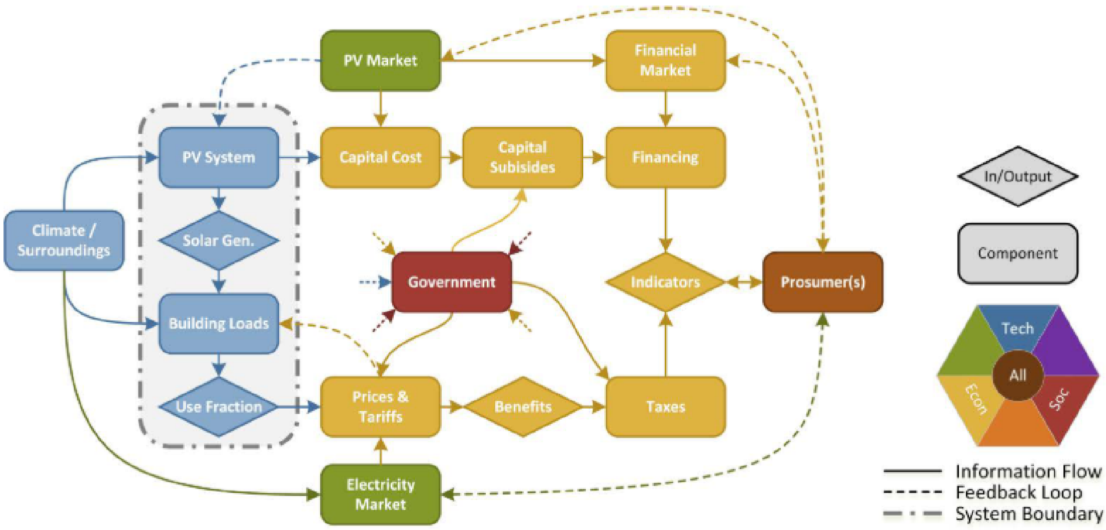

Figure 1.4: Overall view of the solar PV market [Sommerfeldt et al., 2016]

Battery Storage Systems (BSS) are very affected by the situation of solar PV .In particular, barriers affecting PV deployment are also relevant for BSS. BSS can bring many benefits to users, including technical aspects (capacity firming, frequency regulation, voltage support or peak-shaving) and economical aspects such as the possibility to manage power tariffs in a more effective manner. However, their investment cost is not justifiable neither by companies nor households. According to [Ollas et al., 2018] batteries utility depends on the difference between the prices of purchased and sold electricity. As it is now in Sweden, that difference does not justify the investment. This situation could change in the future with the introduction of electric vehicles or a larger share of solar into the market, leading to more fluctuations in electricity prices [Ollas et al., 2018].

Furthermore, the integration of Smart Grid technologies has the potential to improve the welfare of the local electricity installations, and generate better conditions for adopters. In the case of households, it has a great potential in the integration of other technologies such as Electric Vehicles (EV), ground source heat pumps and electricity management systems [Sommerfeldt et al., 2016]. This will also have benefits for the electricity grid, as it will allow for a better balance of local demand and supply cycles [Espe et al., 2018].

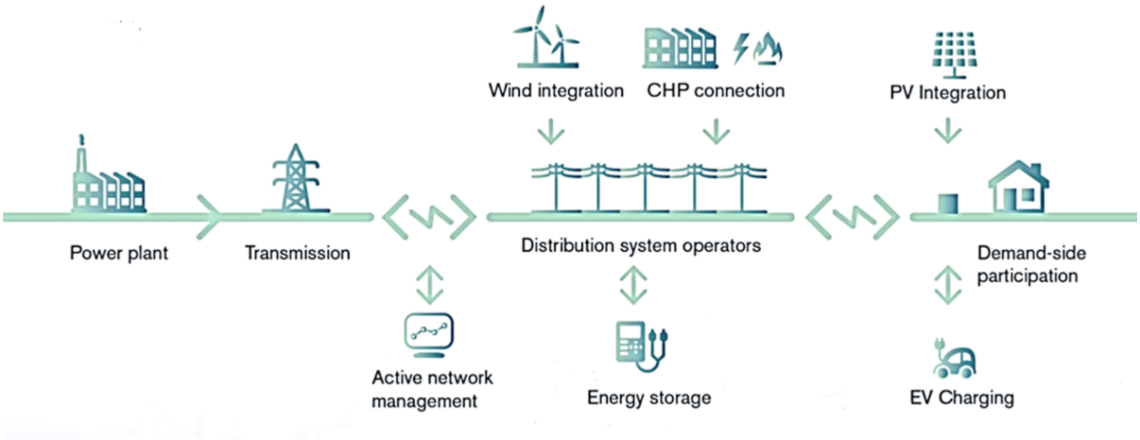

Figure 1.5: Outlook of the future grid

The future for solar PV electricity is still uncertain. The Swedish Energy Commission created in the year 2015 has set an objective of a 100 % reliance on renewable energy for the year 2040 [Lindahl et al., 2018]. This agreement specifies that Sweden must be a net exporter of electricity by 2040. This will imply a gradual phase out of nuclear reactors, which in turn will encourage the production of electricity from RES.

No particular conditions are specified for solar PV energy in this agreement. However, a prolongation of the Swedish green electricity certificate system in terms on facilitating small-scale production of renewable energy will most likely have an impact on the solar PV market [Lindahl et al., 2018]. The Swedish Energy Agency has stated that the share of solar electricity should be around 5-10 % of the total electricity production in Sweden by the year 2040 [Agency, 2017].

1.2 Research Question

1.2.1 Purpose

Extensive scientific research has been dedicated to the deployment of solar PV installations at a household level since this became a trend in the early stages of this century. The large potential for the inclusion of households as micro-producers, together with the need to predict the impact of a massive integration of distributed generation and present realistic solutions to it, have guided the research on the topic.

However, in Sweden the energy market is pointing in another direction. The majority of the solar power being installed nowadays corresponds to installations in commercial buildings. Real Estate companies and housing cooperatives are currently embracing prosumer business models as a way of reducing costs and providing customers with more efficient electricity systems. As a matter of fact, almost half of the installed solar capacity in Sweden is being deployed in commercial buildings. In this thesis, the different economic entities which invest in solar PV technology in the buildings are given the name of non-individual prosumers.

Several questions on the reasons why prosumer companies are interested in solar PV technology arise from this situation. These questions will be answered throughout this project, by studying the following aspects:

- Main drivers that are triggering investments in solar PV among non-individual prosumers.
- Influence of these drivers in the willingness of prosumer companies to engage in solar PV technology.
- Profitability of the investment for prosumer organisations.

This project aims to give research these aspects from a holistic perspective. Through interviews with energy stakeholders, and by deploying a systems approach in order to build two models, the motives and barriers for prosumer companies are studied. Furthermore, the perks and drawbacks brought by prosumerism to the different energy actors such as companies or utilities are presented.

1.2.2 Goals

- Identify prosumer communities in the region of Västra Götaland which are equipped with solar PV and battery storage systems. Conduct interviews with peers from these organisations.
- Probe into the state of the art of energy systems in Sweden and the current situation of the power market. Study the motivations and barriers encountered for different types of prosumers. Get an intuitive understanding of how prosumerism improves the electricity system and the benefits it brings prosumer communities.
- Evaluate the data from the interviews and the literature research and build a conceptual model and a simulatable model.
- Compare the results obtained with the simulatable model with the findings from the interviews and literature research and derive conclusions.

1.3 Outline of the Thesis

This report is structured in eight chapters:

I **Chapter 1. Introduction**: This chapter makes an introduction to the current state of the art of solar energy in Sweden, as well as presenting the research questions of this thesis.

II **Chapter 2. Literature Study**: This chapter studies the literature that has been written regarding prosumerism in Sweden.

III **Chapter 3. Method**: In this chapter the methodology employed to develop this Master Thesis is presented including mixed methods approach, interviews and systems thinking.

IV **Chapter 4. Findings from interviews**: The relevant findings for the research questions obtained from the interviews are presented in this chapter.

V **Chapter 5. Models**: In this chapter, the development process of the Causal Loop Diagram and the Stock and Flow diagram are deployed, together with the final models.

VI **Chapter 6. Results**: The outcome of the simulations and the findings from the conceptual model are presented in this chapter.

VII **Chapter 7. Discussion and Conclusion**: In this chapter the findings from the different sources are compared and cross-matched with the research questions Besides, the thesis is concluded.

VIII **Chapter 8. Future Work**: Potential work to continue the project is proposed in this chapter.

2

Literature Study

This section presents the most relevant literature research conducted on the situation of non-individual prosumers to this day.

For the purpose of the current section, a thorough review on updated sources of information and material has been conducted, mainly articles, reports and scientific papers on the topic.

2.1 The Swedish Prosumer Scheme

2.1.1 Motivations & Barriers

Induced by the uptake of Renewable Energy Sources (RES), the energy market has been undergoing a period of transition. The appearance of innovative business models has allured different kinds of investors and started a transformation which has posed new challenges for the market and the stakeholders of the system [Kubli and Ulli-Beer, 2016, Deliverable, 2020].

The reasons behind adopting renewable technologies are diverse and vary according to the role of the adopter and the type of technology [Bergek and Mignon, 2017]. Previous research has been focused on the motives for adoption of solar PV technology from non-traditional adopters like households, but little research has been dedicated to companies or traditional adopters such as utilities or energy companies [Bergek et al., 2013].

Non-traditional investors such as housing cooperatives or Independent Power Producers (IPP's) own the majority of the installed capacity of solar power in Sweden [Bergek et al., 2013]. As active participants in the energy market, their motives to adopt solar PV are of utter importance to understand its diffusion [Bergek and Mignon, 2017]. The latter are also fundamental for policy makers, as their business strategy shifts according to the motives of investors [Bergek and Mignon, 2017].

Certain patterns are observed in the different motives to adopt solar between non-individual prosumers. [Bergek and Mignon, 2017] identified the factors that are determinant for IPPs and municipalities to invest, being financial motivations primary drivers, together with branding motives or having access to a renewable energy resource.

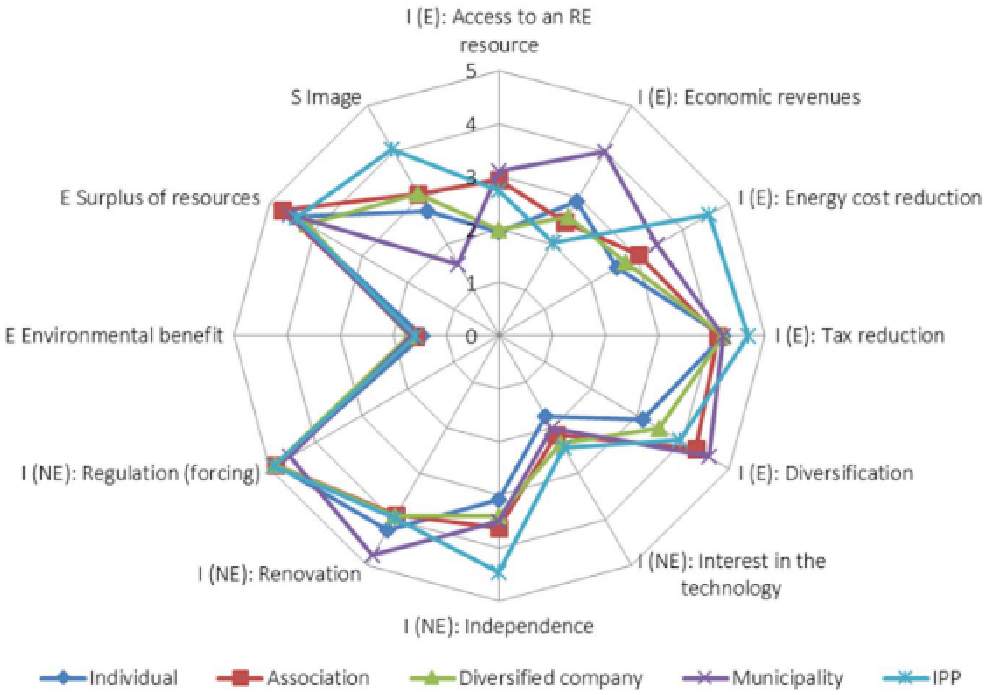

Figure 2.1: Importance of each motive for adoption of RET's , being "1" of decisive importance and "5" no importance at all [Bergek and Mignon, 2017].

[Palm, 2018] studied the motives for household adoption of solar PV and how these are constantly changing and adapting to the market situation. Certain motivations remain constant in time, being environmental motives the most common. Technical interests, increased convenience, economic profitability, self-sufficiency, or protection against future costs were other motives revealed [Palm, 2018]. [Bergek and Mignon, 2017] classified motives into four categories according to the nature of the benefit to prosumers: economic, instrumental , symbolic and environmental motives.

Prosumers motivations are key in the expansion of solar PV. According to [Palm, 2015], the diffusion of solar PV in Sweden has been closely linked to the deployment of public financial subsidies. A similar effect has had the drop in prices of PV technologies, which has been of up to 80% since 2008 [Mayer et al., 2015]. Other factors such as the popularity increase among population powered by the will to access a RES, the growing interest among utilities or the legislation changes in the solar PV framework have prompted the integration of micro-producers into the market [Lindahl et al., 2018].

[Warneryd and Karltorp, 2020] found that current laws and regulations ruling the Swedish market are adapted to the traditional centralized structure. The same applies to the general attitude of the public as traditional grid consumers might present a certain degree of skepticism towards renewable technologies. These factors present barriers and constrain the diffusion of Solar PV energy nowadays.

According to [Palm, 2018], the adoption of solar technology must be understood in a socio-cultural perspective. Moreover, barriers change over time and are specific to the role of the prosumer.

Subsidies, usually considered drivers for adoption, have been recognized to act as barriers themselves. In some cases, they have imposed a cap on the size of the market, as potential prosumers have decided to postpone the investment until subsidies were granted to them, or even in some cases, reject the operation due to the loss of the chance to obtain the subsidy [Palm, 2015].

[Palm, 2018] studied the barriers for household installation of solar panels over a 10-year perspective and concluded that economic hurdles are usually the most commonly mentioned by potential adopters as barriers, including high investment costs, lack of subsidies and long pay-off times. The lack of organizational and institutional support for new technologies was also considered an important barrier [Palm et al., 2018].

Earlier research by [Palm, 2018] disclosed other barriers such as the uncertainty and mistrust in the performance, or the belief that micro-generation requires changes in daily habits, with the inconveniences coming along with them. Aesthetics were also considered important [Palm, 2018].

2.1.2 Prosumer business models

Commercial buildings and multi-dwelling facilities represent around 47% of the total installed capacity in Sweden [Lindahl et al., 2018]. Owners of these buildings are a heterogeneous group ranging from housing companies, tenant-owned associations (BRF's) or Real Estate organisations [Warneryd and Karltorp, 2020].

The legislation affects each prosumer group differently. The current energy market legislation is adapted to the centralized structure, imposing several restrictions to the companies profit aspirations [Warneryd and Karltorp, 2020]. Policies that benefit non-individual prosumers are being deployed slowly, as solar energy is steadily transitioning from a niche technology into a key actor in the market [Warneryd and Karltorp, 2020]. Therefore, the business models for these type of prosumers is bounded to adapt to the current regime.

According to the ownership and business model deployed by a company, the revenue streams are changed, which is a decisive factor for justifying the investment

[Warneryd et al., 2018].

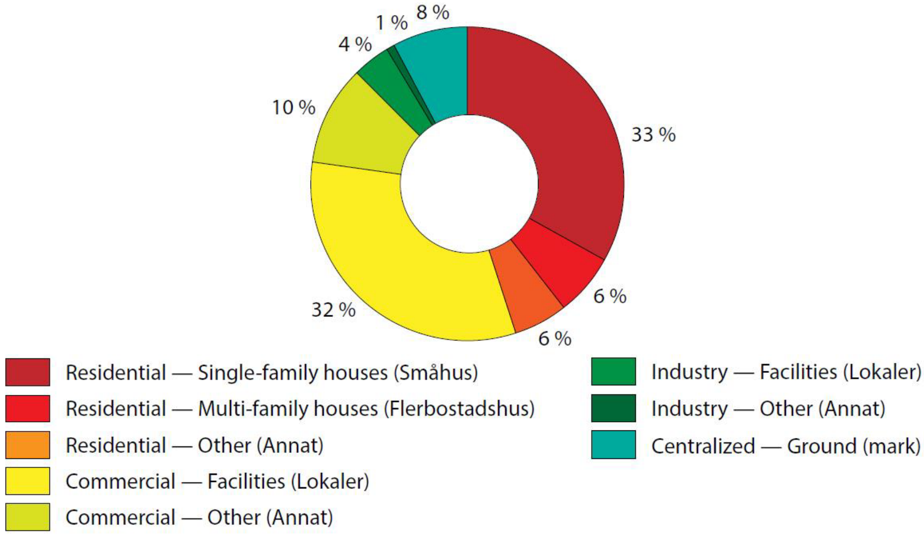

Figure 2.2: Share of installed capacity in 2018 [Lindahl et al., 2018].

Several business models are currently being implement in Sweden. The most common financial scheme for BRFs, housing companies and commercial property owners, is based on the organisation owning and managing the PV panels [Molavi and Bydén, 2018, Warneryd et al., 2018]. According to [Warneryd et al., 2018], this financial model allows for a faster recovery of the investment and a higher profitability than, for example, the leasing contract.

The leasing agreement consists on the company renting the panels from a third party which is responsible for the installation, operation, maintenance and administration of the facility [Warneryd et al., 2018]. The leaser owns the electricity and the user pays a fixed price per kWh of production or a monthly rent, usually at a discounted electricity price, and benefits from not having to commit to a long-term investment [Warneryd et al., 2018]. However, it implies giving up on the possibility of obtaining a profit from selling the surplus of electricity to the grid. An alternative model consists on the prosumer company leasing he ownership of the panels with an investment from a third party, paying a fixed price per kWh to the leasing company [Warneryd et al., 2018]. After the leasing period is over, the panels will be owned by the leaser [Warneryd et al., 2018].

Besides from the mentioned business models, housing companies and commercial property owners are currently offering the roofs of the buildings to external operators to install solar panels on them [Warneryd et al., 2018]. In exchange, they receive a monthly rent.

In the case of Real Estate owners, their business model must be developed in a way that results attractive to the end user and brings cost reductions and other benefits in the long term [Warneryd et al., 2018].

Other known arrangement is the Power Purchase Agreement (PPA), not so common in Sweden [Warneryd et al., 2018].

2.1.3 BSS & Smart Grid

The decreasing retail prices for battery storage systems (BSS) is expanding the market for batteries in Sweden [Lindahl et al., 2018]. In 2018, private households overrun commercial installations in the inclusion of battery systems, powered by the direct capital subsidies for individual prosumers introduced in 2006 [Lindahl et al., 2018]. In Sweden, direct battery subsidies are only granted for households [Agency, 2017]. In the case of non-individual prosumers, a subsidy can be granted for the battery if included in the overall cost of installing PV panels and battery [Lindahl et al., 2018].

Combined with supportive policies, the attractiveness for prosumers of owning a battery is heavily influenced by the difference between purchase and sell prices of electricity [Ollas et al., 2018, Saviuc et al., 2019]. The economical benefit from owning a BSS in the long term not only is dependent on the financial structure, but on the fluctuations of the electricity price as well [Ollas et al., 2018]. Therefore, increasing electricity prices make the investment more alluring for prosumers [Saviuc et al., 2019].

Batteries bring many opportunities to prosumers. Their inclusion creates alternative business solutions, as in multi-dwelling buildings, where housing companies can enjoy an improved management of electricity rates and power tariffs by owning such a system [Sani Hassan et al., 2017]. Batteries are also useful for utility companies by relieving the grid in times of stress and improving the efficiency of Demand Side Management (DSM) policies by shifting loads to properly match the demand and supply cycles [Ollas et al., 2018, Kozarcanin and Andresen, 2018, Espe et al., 2018].

Non-financial welfare of the installation is also enhanced by the use of BSS [Ollas et al., 2018]. From the prosumers perspective, a higher degree of autonomy from the grid or a more resilient system can be achieved by investing on storage systems [Ollas et al., 2018].

Sweden's energy market is liberalised under the so called Behind-the-Meter scheme, which allows for flexibility within the installations [Warneryd and Karltorp, 2020]. Nevertheless, restrictions imposed by the Electricity Act determine the range of influence of battery usage, as taxes apply if production is not consumed inside the grid connection point, impeding the exchange of electricity between prosumers[Warneryd and Karltorp, 2020, Warneryd et al., 2018].

Aggregation is one of the solutions being implemented that could optimize the use of BSS. In this scheme, all the electricity consumption is aggregated around a single point of connection to the main grid, allowing to share the energy between all the tenants inside the building and sharing the cost accordingly to consumption [Andersson, 2018]. An alternative to this model, is the use of produced electricity for consumption in common areas [Andersson, 2018].

The integration of batteries, smart meters and additional devices is supported by the Smart Grid [Espe et al., 2018]. The Smart Grid provides a variety of improvements and solutions to the network, facilitating the bidirectional exchange of electricity and improving the conditions for adopters [Espe et al., 2018].

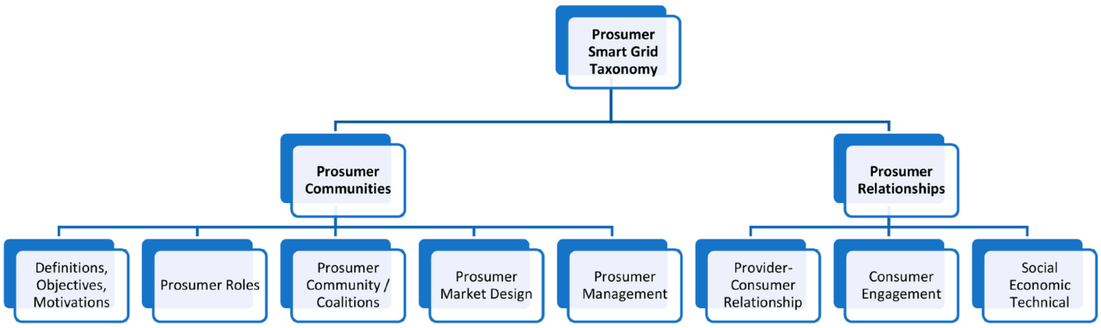

Figure 2.3: Smart Grid Taxonomy [Espe et al., 2018]

The Smart Grid can influence both the economic and technical aspects of micro-generation. For households, there is a great potential as an integrator of technologies such as electric vehicles or energy management systems [Espe et al., 2018]. Moreover, a better management of the variations on the spot price of electricity can be carried out, thus increasing the income from electricity fed back into the grid [Warneryd et al., 2018]. For low voltage residential grids in multi-family buildings, Smart Grid appliances could relieve the grid in times when consumption is low and electricity generation is high [Kozarcanin and Andresen, 2018].

All in all, the integration of Smart Grid appliances creates better conditions for prosumers to enroll in solar PV adoption [Warneryd et al., 2018].

2.1.4 The Role of Prosumers

Several authors agree on the relevance of the role of prosumers for ensuring the viability of the forthcoming network [Warneryd and Karltorp, 2020, Kubli and Ulli-Beer, 2016, Büscher and Sumpf, 2015, Espe et al., 2018]. Prosumers actionability, i.e., their will to become active players and service providers of the system will be fundamental [Büscher and Sumpf, 2015].

Shifting from traditional grid consumers to active prosumers will bring many economic and sociotechnical benefits to the system [Espe et al., 2018]. With their decisions, solar PV adopters will be able provide flexibility to the power market [Kubli et al., 2018]. Acknowledgment of their roles and expectations is crucial for the development of business models, processes and solutions in accordance with the Smart Grid [Espe et al., 2018].

[Palm, 2015] studied the diffusion of solar technology in Sweden from a technological system (TSI) approach. They mined through the underlying network of actors and institutions involved in the process and concluded that, in addition to the importance of power companies, electricity retailers and grid owners to developing a robust network, consultancy firms, architects, construction companies, advocacy organisations, local authorities and urban planners efforts were of utter importance.

2.1.5 A Decentralised Future

One of the consequences from distributed generation is decentralisation of the production. As the market for solar evolves, decentralisation will happen [Kubli and Ulli-Beer, 2016]. Local and micro-generation of electricity are decentralizing the production of electricity and inducing the need to seek for innovative solutions for the traditional stakeholder organisations [Kubli and Ulli-Beer, 2016]. Understanding the decentralisation dynamics is crucial for long-term planning, adoption of business models and grid maintenance on behalf of utilities, technological companies and politicians [Kubli and Ulli-Beer, 2016].

Utility companies are particularly affected by this situation. Their traditional business model is based on future estimations of the electricity used by the consumer. Fluctuations in demand induced by distributed generation will inevitably destabilize their rooted revenue model. This could contribute to an increase in grid prices in order to ensure investment recovery [Kubli and Ulli-Beer, 2016]. Thus, electricity price would also be affected.

An increase in electricity prices could bring many negative aspects both to prosumers and energy companies. As the price would be higher, a higher deployment of solar would be expected, raising the price even more. This is known as the utility death spiral shown in Figure 2.4.

Increasing electricity prices will affect Grid Parity, the equilibrium point when the levelized cost of electricity (LCOE), or the price at which electricity must be generated from a RES to break even over its lifetime, is equal to the price of the purchased electricity [Palm et al., 2018]. It might then become more profitable for micro-producers to directly consume their self-produced solar electricity instead of feeding it into the grid [Ecker et al., 2017].

Decentralisation, increased higher rates in the adoption of BSS and the expansion of the Smart Grid will inevitably lead prosumers to rely more on self-produced

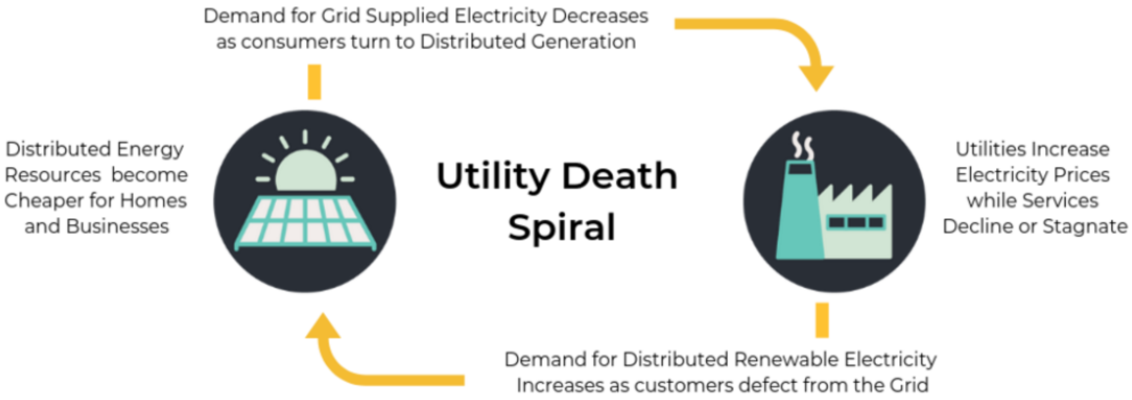

Figure 2.4: Utility Death Spiral

electricity and less on the grid [Ecker et al., 2017]. This will potentially induce a higher degree of autarky, understood as a combination of factors such as independence, autonomy, self sufficiency or control of the situation [Ecker et al., 2017].

The development of the Smart Grid and the integration of other appliances will increase the will of small-scale investors to become independent and could lead to the growth of Micro-grids [Kubli and Ulli-Beer, 2016].

3

Method

This section presents the methodology and tools employed to collect the data used to develop both a conceptual and a simulatable model.

As explained in Section 1.2.1, the purpose of this thesis is to identify the motives and barriers that non-individual adopters of solar PV panels encounter when developing prosumer business models in multi-dwelling, multi-purpose and commercial buildings, as well as to analyze the benefits brought by prosumerism to these communities.

The scarce research deployed in this topic has determined the methodology used for this project. Induced by the need to attain more information on the motivations and hurdles for organisations, it was decided to contact companies with experience in the solar PV market, i.e., prosumer companies. To gather the data, semi-structured interviews have been conducted. The reason to choose interviews instead of other methods such as online surveys or online questionnaires lies on the need to have accurate responses to the questions asked, as this qualitative data was meant to be used to develop a conceptual model. This part is considered the primary methodology of the project, exposed in Section .

In parallel, quantitative data has been obtained through literature research on scientific papers, articles and other technical documents, considered as the secondary methodology to this project, reviewed in Section 4.

Being non-individual prosumers such a heterogeneous group, e.g., Real Estate companies, Tenant-Owned associations or project developers, the data gathered from the interviews has been very diverse and referred to different subjects. Each and every interviewee has provided their personal point of view and empirical experience on the questions asked. In consequence, the amount of information collected has been substantial.

Altogether, the information from the interviews and the literature research has provided a thorough insight of the situation for companies. Nevertheless, to extract those aspects which are most relevant to the research question, and merge the different findings, an structured methodology has been necessary. In consequence, a mixed-methods approach has been deployed, based on the systemic integration of the quantitative and qualitative data. By using this approach it has been possible to facilitate the process of extracting the findings from the interviews and compare them to the findings from the literature research. As a result, the variables and underlying feedback relations between them have been uncovered to develop a conceptual model and a simulatable model with the factors that affect the prosumer scheme in Sweden.

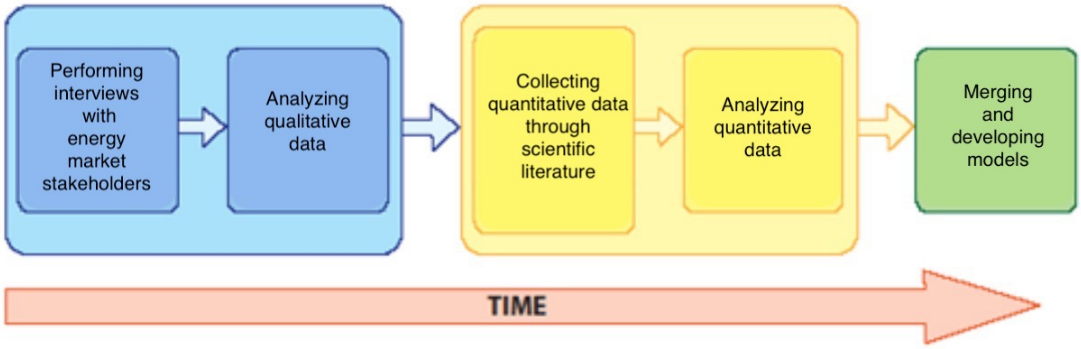

Figure 3.1: Mixed-methods research method for this project

The conceptual model has been designed as a Causal Loop Diagram (CLD), whereas the simulatable model has been implemented as a Stock and Flow diagram (SFD). Both models have been implemented upon a systems approach, which facilitates the integration of the information in a structured way by relying on the ability to see things from a holistic point of view. Systems are treated as complex nets of connections and relations, were every variable can influence or be influenced by others in the system.

This is precisely what System Dynamics (SD) strives to do. SD is a method to analyze, study and develop models that can encapsulate some kind of real behaviour or pattern. It does so by examining the inner relationships between variables and presenting the loops that are natural to them. For this reason, it has been considered the optimal way to address the research question.

Furthermore, in parallel to the development of the models, a business case analysis has been conducted to study the profitability of prosumer companies operating in the area of Västra Gotäland.

3.1 Qualitative Data Collection: Interviews

Interviews have been the primary source of qualitative data for the development of the model. Conducted both on-site and online, they have consisted of semi-formal meetings of approximately one hour of duration. In each of the interviews, a set of predefined questions has been asked, with the purpose of obtaining the interviewee's personal and corporate point of view on several aspects surrounding prosumerism. These questions are presented in Appendix A. Upon agreement between both parts, interviews have been recorded through a mobile phone for further transcription and better evaluation of the information, under the condition of remaining anonymous.

The topics addressed in the interviews have been many, and customized according to the role of the interviewee. A first battery of questions has striven to get a grasp on the degree of satisfaction from the organisation with the projects that had been developed until the moment of the interview, apart from the motivations and barriers encountered when developing them and the possibility of implementing the same business models in further projects.

A second set of questions probed on the interviewees personal opinion of the current situation of the solar PV market in Sweden, and the convenience of enrolling into prosumerism. Some final questions delving into the likelihood of an uptake of battery storage systems, the role of prosumers as grid helpers and the prospects for the future energy market in Sweden complemented the questionnaire.

A total of 6 interviews have been conducted. All the findings and information obtained can be observed in Section 4.

3.2 System Dynamics

The real world, as complex as it is, presents itself as an arbitrary, stochastic and in most cases, unpredictable environment. Extrapolating real dynamics to fabricate conceptual or numerical models usually implies a thorough understanding of the reality being modelled. Through deep knowledge of the system, variables can be defined and underlying interrelations can be uncovered. This process is not always easy and can present several complications proper to the complexity of modelling that reality.

System dynamics (SD) is a method that provides a technique for the creation and implementation of realistic models through a systems approach. These models can represent complicated structural engineering problems or more simple everyday problems. In words of [Pruyt, 2013], "System Dynamics (SD) is a method to describe, model, simulate and analyze dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies".

The objective with SD is then to identify the weak spots of the system's infrastructure, which are acting as barriers, and apply the necessary changes to improve the undesirable behaviours. System dynamics supports that problems are inherent to the system's structure, and thus, by changing the structure, the problem can be solved.

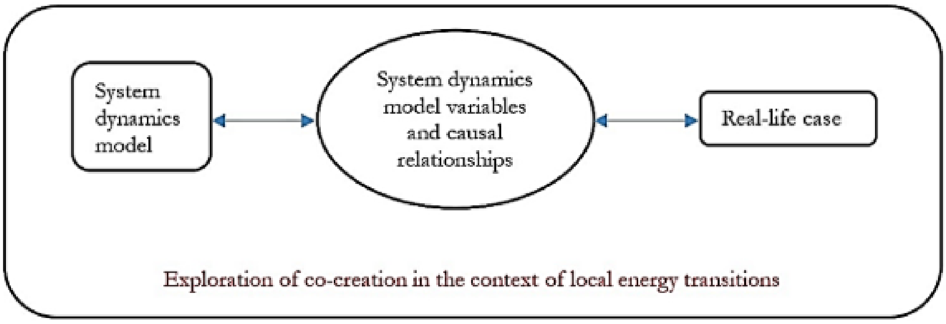

Figure 3.2: System dynamics modelling [Selvakkumaran and Ahlgren, 2018]

Different types of models can be created by deploying a system dynamics approach, according to how the underlying relations want to be presented. For model conceptualization, a Causal Loop Diagram is the suitable representation, whereas a Stock-Flow Diagram is more optimal for simulation and data testing.

3.2.1 Causal Loop Diagrams and Stock-Flow Diagrams

SD addresses the relations between variables through the causal relationships that naturally relate them. In a Causal Loop Diagram (CLD), the causal influence between variables is expressed with arrows going from one variable to the other, which can be positive or negative depending on the increasing or decreasing effect of one variable on another.

Each variable induces an effect on another via an arrow. The arrowhead indicates whether this effect is positive (+), meaning that it induces an increase in the receiving variable, or decreasing (-), meaning that it decreases it.

Relations between variables can create balancing or feedback loops. Balancing loops occur when the net effect of the causal links within a loop is negative, i.e., if the number of '-' signs is uneven. If the contrary happens, then a reinforcing loop is present. Reinforcing loops contain at least one stock or delay variable which functions as a memory in the loop. Delays are related to the natural time frame of influence between variables.

CLDs are useful to understand the global behaviour of a system and observe the interactions between variables. Nevertheless, these diagrams lack to provide a better understanding of the impact of each relation as they do not quantify it. In addition, they do not give a good understanding of how units accumulate over time.

SFDs, on the other hand, are dynamic and provide the basis for numerical analysis. Given a set of initial conditions, and implementing the corresponding equations that model how each variable relates with the others, behaviour in time can be observed. SFDs do not include polarities as they do not target loop analysis. Alternatively, they focus on stocks and flows.

A stock or state variable is that which accumulates over time and has an absolute value. It is increased or decreased by one or multiple inflow or outflow rates, respectively. The net rate of change of a stock is the sum of all its inflows less the sum of all its outflows. Distinction between stock and flows is not straightforward in some cases, and must be done for proper assessment of the model.

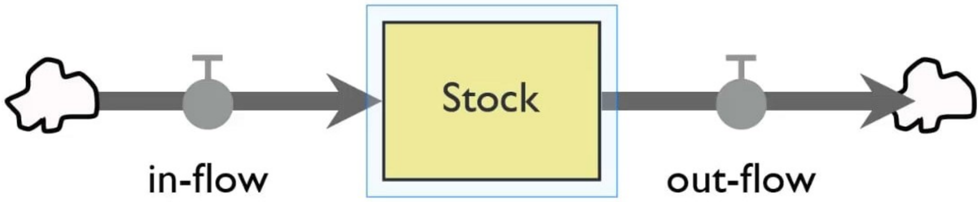

Figure 3.3: Simple Stock and Flow structure

SFDs are, thus, optimal when simulating the behaviour in time of a system. The great advantage of SFDs is that they allow for simulating abstract events, providing a tool for the designer to define the interrelation between variables. As main drawback, SFDs fail to provide an overall vision of the system and can overload if too many numerical details are provided.

To develop these models, the software Vensim from Ventana systems has been used. Vensim is a mathematical tool that provides an interface for the creation of both conceptual and simulatable models. This software emphasizes in model quality, connections to data, flexible distribution and advanced algorithms.

4

Findings from interviews

This chapter presents the findings revealed from the interviews with the prosumer organisations. Four sections are presented, according to the subject covered by each of them.

4.1 Motivations for Prosumer Organisations

Installing solar panels in multipurpose buildings has emerged as a way for companies and housing cooperatives to give an added value to the service they provide to the customer. The mentality for some project developers towards solar technology has changed and evolved to the point were panels are no longer considered as an alternative, but as binding elements of the infrastructure. According to one of the interviewees, some years ago, newly developed projects considered solar panels as a possible add-on. Instead, induced by a general shift in attitude towards solar, every newly develop project takes them into account in the project plan.

The motives to install these panels have been found to be of different natures according to the type of prosumer and their role in the electricity system. Companies motivations behind engaging in the solar PV market are different than other types in prosumers, as they do not enjoy the same benefits. As an example, companies are not offered the same economic incentives as households. Therefore, their willingness to invest must be motivated by other factors alluring enough to convince them to invest. Reducing electricity costs has emerged as a triggering factor for PV deployment. Installing solar panels is a way for companies to reduce the electricity consumption within the building. This way they can lower their electricity bill by having a better control over costs. Together with lessened costs, feeding the surplus back into the grid is a way of obtaining tax reductions, currently specified for Sweden in 0.60 SEK/kWh. However, despite the existence of these tax exemptions, most of the companies interviewed claimed consumption within their buildings to be high enough to barely overproduce any electricity, meaning that only small amounts were being fed back into the network, only in times of peak generation like the summer.

Another relevant economic driver for adoption are subsidies. Subsidies are granted in Sweden for both individual and legal persons for a 20% of the total installation cost, with a maximum of 1.2 million SEK per installation. This significantly lowers the investment cost, specially important for smaller companies. However, according to some peers, subsidies usually take from 1 to 2 years long to be received, what makes it difficult to take them into account when developing the budget for the project.

Other financially relevant factors for PV diffusion are the decreasing costs of PV panels and the potential increase in electricity price, following the trends from the past twenty years. The fear for higher prices in the future was mentioned as another motivation to install the panels.

Aside from having a better control of the electricity system in the building, self produced electricity turned out to be a recurrent motive among prosumers. According to one of our interviewees, this is related to having a higher influence on the local installation and improving the knowledge of the electricity system. It is a combination between reducing costs and controlling them, *"you know a little bit more about how much energy demand will cost having their own production"*, claims.

Producing renewable electricity was found to generate a feeling of satisfaction among prosumers through an increased contribution to environmental matters. As a matter of fact, it has become clear that environmental concerns are very important drivers for adoption among companies operating in Sweden. Sustainability initiatives impulsed by the government, such as the 100% reliance on renewable produced electricity objective for 2050, have had an impact on consumers, which picture prosumerism as a way of contributing with their grain of sand towards sustainable development.

Being sustainable is also a marketing strategy for companies. Investing in Renewable Energy Technologies (RETs) is a way to improve the image of the organisation and profile it as being sustainable. In consequence, companies are seen as more attractive in the eyes of potential customers who want to experience the personal pride of consuming clean electricity.

As a matter of fact, giving customers an upgrade in their energy system turned out to be an important motive as well, aimed at ensuring customer satisfaction with the ultimate goal of creating a higher loyalty to the organisation.

Finally, a higher autonomy and self-sufficiency from utilities emerged as another motivation, induced by the dissatisfaction of some prosumers with the services provided by local grid owners.

Table 4.1 shows the motives exposed according to their origin.

Motives for Adoption	**Economic**	*Electricity cost reduction* *Tax reduction* *Subsidies* *Uncertainty of future cost of electricity* *Lowered prices of PV technology*
	Environmental	*National sustainability initiatives* *Individual sustainability goals*
	Instrumental	*Upgrade conditions for customer* *Produce own electricity* *Contribute to the local energy system*
	Symbolic	*Self-sufficiency* *Branding*

Table 4.1: Motives revealed in the interviews

4.2 Barriers for Prosumer Organisations

Being Sweden a country with a historical dependence on nuclear power and hydro power, and influenced by the conviction that the weather conditions in the country make it unsuitable for solar electricity production, the diffusion of distributed solar generation has traditionally encountered much skepticism among the citizenship. This has presented itself as a huge barrier, as it was mentioned by some of the interviewees.

High prices of PV technology, absence of companies that would provide the installation, or bureaucratic obstacles were some of the barriers that prevailed in the past. The appearance of new actors and the surge of new business models in the energy market have abated some of the traditional barriers and induced the apparition of new ones.

It has become clear that certain traditional barriers still affect prosumers nowadays. One of them is the price of solar panels. Despite the significant decrease of the price of PV technology in recent years, the high investment cost is still an important barrier. In general, economically driven projects are constrained to really tight budgets. When financial complications arise in the projects, panels can be the first element to suffer the consequences. As one of the interviewees points out, *"the easiest way to adjust the budget is by removing those things the customer does not see"*.

The high cost poses a challenge within the prosumer company as certain peers might show some reticence to embrace the investment. This creates delays in the implementation of the projects. One of the peers commented on the usual difficulties they found to convince their bosses to give the green light to the installation of the panels.

Real Estate companies and housing cooperatives must have the financial sufficiency and long term stability to face the investment, since long term planning is crucial to ensure its profitability. Some of the peers stated the utter importance of ensuring that no unexpected extra costs associated to maintenance labours or roof issues, that were not accounted for in the budget of the project, would have to be faced throughout the lifetime of the system.

Therefore, proper planning is fundamental to ensure the viability of the business model, specially in Sweden where the electricity price is very low in comparison to other European countries. Payback times for solar investments are long. The companies interviewed aimed to recover the money in approximately 15-20 years. Subsidies are meant to contribute to this situation and relieve the burden from the high investment cost. However, not always they manage to do so.

The lack of a supportive legislation framework has emerged as another significant barrier. Several interviewees agreed on the fact that the current policies being implemented by Svenska Kraftnät lack to encourage distributed generation, as they impose many legal barriers on both companies and utilities. One of our interviewees pointed out the fact that, as the interest from traditional customers in solar energy has become larger in the recent years, the difficulties and barriers imposed by the Swedish Energy Agency and the politicians have grown accordingly: *"then it becomes sort of a real threat to establish a real system and it brings more conflict"*.

The lack of incentives is a big issue for prosumer companies. Aside from tax reductions, companies are not being incentivized to produce electricity. As an example, no other compensation for feeding electricity back into the network is given to companies on top of the spot price. What is more, restrictions such as the cap of 255 kWh of maximum installed capacity are imposed, creating a grim picture for potential adopters.

Utilities are also not encouraged to help the system. According to one of the agents, *"There are no incentives for grid companies to help the system. Instead, all they have are power tariffs"*. In addition, utilities business model is constrained. With the current regulations, utilities cannot own storage systems other than for frequency control. *"The grid company cant own storage or batteries other than frequency regulation. Then you cant really work with those as say, local energy balancing"*.

The failure to adapt the legislation framework and present innovative solutions is associated to a rooted traditional mentality against RES as being the main player in the energy market, as one of our interviewees mentions. A large amount of electricity consumers still believe nuclear power is the solution to the challenges posed by the future. This presents a serious barrier towards the implementation of new policies that facilitate the integration of renewable energy and the development of new laws.

This attitude is rooted into public institutions. *"I think Svenska Krafnät definitely has a traditional investment model, a capacity building model, which definitely needs to change"*. However, most of the companies agree that it is a process of awakening. *"From a transition perspective it is natural to have these conflicts between established regimes and newcomers, so that it just shows that it is going forward"*. The legislation changes will be introduced slowly impulsed by the pressure put on these institutions to update their attitudes and models.

Barriers	*Investment Cost* *Long Pay-off Period* *Lack of incentives to sell electricity* *Cap on power installation* *Lack of a supportive legislation framework* *Lack of incentives for utilities* *Individuals Reluctance* *Conflicts between actors*

Table 4.2: Barriers found in the interviews

4.3 Benefits & Drawbacks for Stakeholders

Installing solar PV panels in commercial and multi-housing buildings has been found to improve the overall welfare and status of the companies in different ways.

The economic benefits are the primary source of benefit for prosumer companies. Despite the high investment cost and large payback time, their prosumerist model is expected to bring profits to the company after 15-20 years. As one of the interviewees claims, *"It is going towards an economic benefit, definitely, you can get cheaper electricity for your own sake"*.

The installation of the panels also brings within environmental benefits proper to the reduction of the carbon footprint of electricity: *"you now have an environmental benefit, you are providing an environmental solution which will reduce impact on the climate issues"*, he argues.

Customer engagement, increased knowledge of the energy system and increased cohesion in the community have emerged as other consequences of installing the panels. As one of our peers mentions, *"if you are a multiple building or a community or something like that, then you can have benefits like increased cohesion in the community, social awareness, also often I have seen people that learn more about the energy system"*.

This is applicable for the case of housing cooperatives in Sweden, or Bostadsrättsföreningen (BRF's) owning multi-dwelling buildings. For these associations, a higher satisfaction from dwellers translates into a higher enrollment in the electricity system and, in consequence, reduced electricity consumption and increased effectiveness of Demand Side Management initiatives. Altogether, they can relieve electricity system from the stress generated in times of high demand and reduce the costs of electricity within the building.

In the case of commercial or multi purpose buildings, customer satisfaction with the system turned out to have increased from the use of renewable electricity, despite in most cases, the customer was still paying the same price as before installing them; an increased contentment from customers results in a higher loyalty and bonding to the company, what can ensure the viability of the prosumers business model in the long run and favour the connection between prosumer and end user.

Installing solar panels triggers a higher interest and engagement of the employees within the organization in electricity matters, as it has been mentioned by several interviewees. An emerging feeling of pride rises among the employees for belonging to a company which produces their own renewable energy. It also creates a feeling of induced innovativeness. All in all, these factors facilitate the cooperation between departments within the company, what translates into less resistance for the deployment of solar panels in future projects.

Certain conflicts inherent to the relationship between building owner and customer can arise from prosumerism. Among these conflicts, the ownership of the panels was a recurrent one. Customers, in some cases, want to claim that the panels are their own for branding motives. In this case, companies can offer them the possibility to "lease" the ownership of the panels during the period of agreement in exchange for a prearranged sum of money. This solution solves the problem and promotes customer satisfaction.

Local grid owners can also see themselves benefited by the installation of the panels, as they reduce the capacity needs in the network and help the grid with regulating the fluctuations happening in situations of peak demand. Furthermore, prosumers need to pay a tax to utilities for installing the electricity meters and using the net, what translates in an increased revenue for the utility company. This induces the need for better communication between grid owners and prosumers, needed to get the system working properly. *"I have seen local energy companies that have been working a lot with solar PV that have also sort of deepened their relation with their customers in a positive manner, talking a lot more, having a tighter relation which is beneficial"*, claims one of the interviewees. In consequence, a better relation can enhance the possibilities for both parts.

On the other hand, utilities revenue streams will potentially be curtailed with an uptake on the number of microproducers. The network price is a combination of the variable price depending on the fuse size, i.e., on the capacity installed for the building, plus the variable price, dependent on grid consumption. Therefore, less capacity requirements in the building, together with a lowered demand, will result into decreased revenue for utilities.

At a microscopic level, this could most likely be dealt with by utilities. However, a significant amount of panels being installed over the country could potentially put utilities business model at risk. In theory, an increase in the number of prosumers would compel utilities to rise prices to cover their costs. This would result in a decrease in satisfaction from grid users with the system and a higher will to be autonomous from it, increasing the demand for solar technology. An increase in the latter would reduce the price of solar panels, meaning a higher likelihood to embrace prosumerism. This loop is known in literature as the utility death spiral.

Technical issues will arise from distributed generation. The bidirectional flow of electricity complicates the model of the network and could make utilities lose control of the system. To avoid this, mechanisms must be implemented which take this aspects into consideration, both at a technical and a financial dimension. According to one of the peers, *"It is not just how they create the earnings but it is also how they do their activities, their daily activities"*.

Utilities will need to adapt to the changing role of the grid and be prepared to experience a change in their dynamics. New solutions and agreements will have to be proposed by grid owners to create a robust infrastructure. These will require both modelling and investing in new technologies as well as developing new policies and adapting to the existing ones. *"It is a bit more challenging, at the same time they are losing earnings for their previous sales"*, claims one of the interviewees.

Prosumerism also brings benefits to the wider society. It is likely that more involvement from the population in energy matters would translate into more environmentally friendly citizens making a smarter use of the electricity, and consequently reducing the consumption of electricity. This goes towards the objectives set by the country to shift their electricity production to depend exclusively on RES by the year 2050.

On the other side, some drawbacks for the citizenship related to prosumerism have been pointed out. An uncontrolled transition into decentralised production could generate problems for companies rooted in the current energy regime. All these stakeholders, producers, utilities and energy companies might lose their businesses with the consequences on the employees and peers dependent on their wellfunctioning. Therefore, the transition into microgeneration must be done gradually and according to the needs and requirements of both the current actors in the system and the newcomers, in a way that prosumers are engaged and attracted by what is offered to them and traditional companies still receive a piece of the cake.

4.4 The Role of Batteries

Higher penetration levels of renewable electricity will present several challenges to the energy stakeholders. Utilities in particular will be really affected by this situation. The fluctuations induced by excessive amounts of electricity being transferred to the grid at the same time could bring many problems to the local networks.

In order to face this complex situation, batteries present themselves as an optimal solution. Through the use of storage systems, flexible solutions for the future network can be provided. Furthermore, batteries can be utilized as regulators of the DC system within the installations. *"I see a great potential to help the grid with flexibility services and frequency control"*, comments one of the interviewees.

Despite the many technical benefits, batteries are still not considered as a worthy investment for prosumer companies. Most of the organisations that were consulted argued that batteries involve an excessively high investment cost for what they give in exchange. One of the interviewees even commented the following on the possibility of including batteries: *"we do not have any buildings with battery storage. I haven't seen any solutions which have resulted in good investments yet. It is very expensive"*. Recycled batteries could be a solution to this problem, as they represent a sustainable solution that removes the problem of the investment cost.

Besides the high investment cost, the current legislation does not encourage prosumers to invest in batteries. The lack of incentives for companies encouraging them to give electricity back to the grid together with the restrictions on power, create harsh conditions for prosumers. As a consequence, large buildings barely overproduce any surplus of electricity due to as the whole production is dedicated to fulfill the elevated consumption within the buildings. This neglects the need for storage.

Utilities are also affected by this situation. The current legislation framework constrains the possibilities for the use of batteries for local grid owners. The Swedish Energy Market, liberalised under the behind the meter scheme, allows grid users to share electricity within the same electricity meter in Sweden, but forbids the transportation of electricity from one installation from another. As a consequence, utilities cannot use the electricity produced in one place and transport it to another.

Should these restrictions be depleted, aggregations could emerged as an alternative. Several buildings sharing one or more batteries owned by a utility company could be a solution for the deployment of battery storage systems to improve the overall well-being. Aggregating resources would require cooperation between the different companies. *"I would say that helping collective solutions between several households or buildings should be encouraged rather than what happens today, were it is very much me, myself and my meter"*, claimed one of the peers.

On the other hand, aggregations within local installations are permitted in Sweden. Multi-apartment buildings where the electricity would be payed for as a whole, with a single connection point to the main grid, could take advantage of this situation and use battery storage to upgrade the system.

This is the case for micro grid owners. One of the companies that participated in the interviews was both a Real Estate owner and a micro grid adopter, as part of a pilot project. Batteries were used as a way of improving the welfare of the system, but were never considered as a tool to become autarkic. Anyway, owning a microgrid gave them the possibility to share the electricity between the interconnected facilities. *"In this area we consume always our solar electricity, we don't sell it out. So then you can ask why do you have batteries here, but then it is a learning process, the batteries are also here to get the DC systems working better"* was mentioned.

As a consequence, batteries are mainly being used in experimental projects. Through the implementation of these pilot projects, companies receive funds for investigating about the benefits that batteries bring to the system and are encouraged to develop test beds with batteries.

5

The Models

In the current Swedish Solar PV energy market, prosumerism is most extended between companies and households, which own most of the share. The reasons for them to adopt PV panels are very heterogeneous, and depend on the way they conceive the investment. As an example, individual adopters see solar panels as a possibility not only to obtain cost reductions, but also to gain a revenue through the electricity they feed back into the grid. As a matter of fact, the existence of these incentives for households is key in their willingness to adopt. On the other hand, this possibility is not present for organisations, which do not enjoy the benefits of feed-in tariffs. Companies, on their behalf, are customer oriented, being client satisfaction one key driver for adoption.

Household motivations have been taken into account in the early stages of the development of the Causal Loop Diagram, as little information addressing companies had yet been extracted from the interviews. After analyzing all the information available, some common motivations to households and organisations have been found and therefore been included in the model. Those which were unique to households were removed.

The conceptual model has been built following an iterative process driven by the findings from the interviews (see Section 4) and literature research (see Section 2.1). The introduction of new variables created additional loops which subsequently contributed to uncover certain underlying relations that had not been acknowledged in past iterations.

In consequence, this has posed challenges, such as understanding when one variable could affect other in different ways, or how the relevance of previously defined variables had completely changed when introducing a newly found variable. In the end, the inclusion of new variables has helped to extend the boundaries of the model and refine it to better represent the reality that was being modelled.

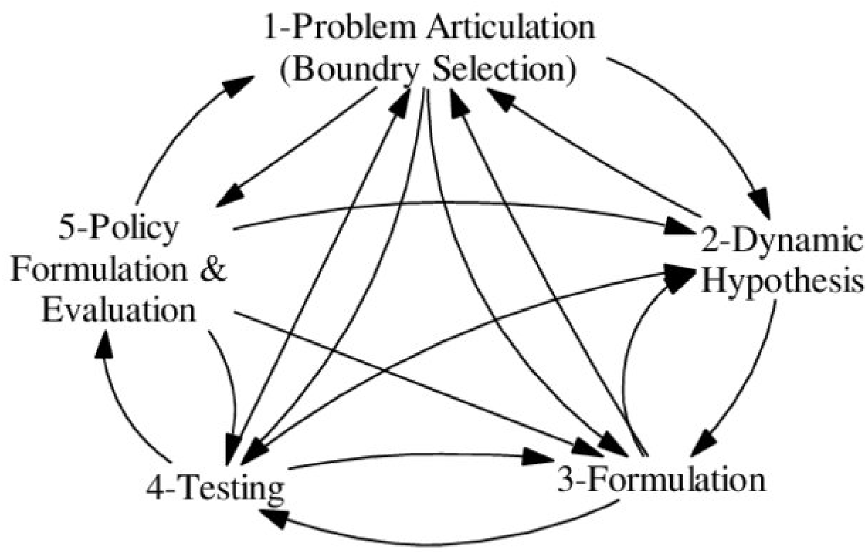

Figure 5.1: Iterative and feedback modelling based on system dynamics [Sterman, 2004]

The CLD has been built by deploying a holistic perspective to the research question (see Section 1.2.1). The system encapsulates the influence that motives and barriers have over different types of prosumers, and it does so from an external perspective to the system. As a result, the resulting system does not target the dynamics of an specific type of prosumer, but it can be applied to the whole range of non-individual prosumers. Whenever some variable or factor is targeted at a specific group, it will be clearly outlined.

Furthermore, the CLD has been modelled as a combination of sociotechnical and socioeconomic factors. For this reason, the model combines variables which refer to quantifiable factors and variables that address non-quantifiable aspects. The relations between both types of variables can easily be represented in a conceptual model, since the model does not require quantifying the relations. However, this has posed a major challenge in the modelling process of the Stock and Flow diagram.

Due to the difficulty inherent in providing a broad image of the motivations and reasons for prosumer organisations to enroll in solar PV just by developing a conceptual model, the decision to implement a Stock and Flow diagram was taken. Owing to this, not only the causal relationships could be outlined, but also quantified.

The Stock and Flow diagram has been modelled as a simplified representation of the reality modelled with the conceptual model. The underlying relations and feedback processes exposed in the CLD have been kept to the maximum extent possible, regardless of the difficulties in quantifying them. However, some relations have indeed been neglected, and some others have been simplified in order to make possible the realisation of the SFD.

Being dynamic, this diagram allows to observe how the evolution of certain variables affect prosumerism in time. This is precisely what is intended. Rather than observing how the individual prosumer has benefited from using the panels, the goal is to understand how the variables will evolve in time, and how this will affect the perception of prosumerism and influence the rates of adoption.

The model is a mix of behavioral, technical and economical factors. All the variables have their own units, and are linked to others through predefined equations. In some cases, these variables are defined with a preset value, which can be a constant or can change in time. Those which do not have an initial value, vary according to the changes in the variables affecting them. To achieve unit consistency, it has been necessary to include additional unit parameters. All the variables, units and equations are shown in the Appendix A.

With regards to the notation used in Sections 5.1 and 5, all the names representing variables of the model are presented in bold letters.

5.1 Conceptual Model

As it has emerged from the interviews, it all starts with wanting to become a prosumer. The initial willingness for companies to enroll in solar energy business models has been considered as the point of departure for building up the model. This first component or variable has been modelled through the **Will to become a prosumer** variable. The rest of the model has been developed around this concept.

The **Will to become a prosumer** leads to an increased intention to collect **Information of solar**, which represents the process of gathering information on the virtues and benefits of owning solar panels. In turn, this contributes to a higher **Likelihood to become a prosumer**. This is considered the moment where the company has to decide whether to carry on with the operation or call it off. This decision depends on many other factors which will be presented throughout this section.

Assuming the decision from the potential prosumer is positive, the **Likelihood to become a prosumer** will lead to a **Prosumer**. A balancing loop is formed as the **Prosumer** variable decreases the **Will to become a prosumer** in the organisation. This can be observed in Figure 5.2.

Becoming a **Prosumer** triggers certain attitudes in individuals. Generally, our peers agree on the increase of welfare that the panels brings to their electricity system, what contributes to a higher satisfaction of the agents involved. In consequence,

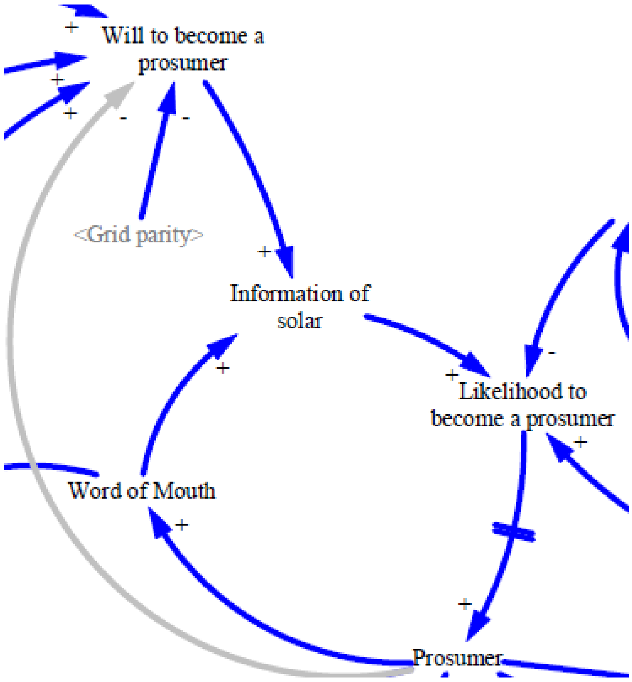

Figure 5.2: Balancing and Reinforcing loops

these people will spread the word among others who are interested in having solar panels. This has been modelled as an increase in the **Word of mouth** factor, which at the same time, enhances the **Information of solar PV**. In consequence, a reinforcing loop is closed which represents the reinforcing nature of the increase of knowledge on the benefits of solar with the uptake of the demand of this technology.

Both the reinforcing and the balancing loop just mentioned address the transition that a prosumer organisation, be it a Real Estate company, housing company or another, undergoes from the moment it considers installing solar panels to the instant these are already installed and producing electricity. They are considered to be the core of the system, as every potential adopter is expected to follow the steps of gathering information and then becoming a prosumer while at the same time being influenced by the Word of mouth.

The motives for these companies to adopt have been been presented around the **Will to become a prosumer** of potential adopters, as they are considered to have an effect on potential adopters willingness. Motives have been separated into four categories: economic, instrumental, symbolic and environmental. Deeper explanation on the nature of each motive can be found in Section 2.1.1.

Environmental motives are considered to have two dimensions. An individual dimension refers to the individual organisations or companies, whereas the national dimension refers to governmental policies in environmental concerns. The latter affect the perception of this problem in consumers. Thus, the **Sustainability goals**

at a national level contribute to an increase in the **Sustainability goals at an individual level**. In consequence, the **Environmental motives** increment the **Will to become a prosumer**.

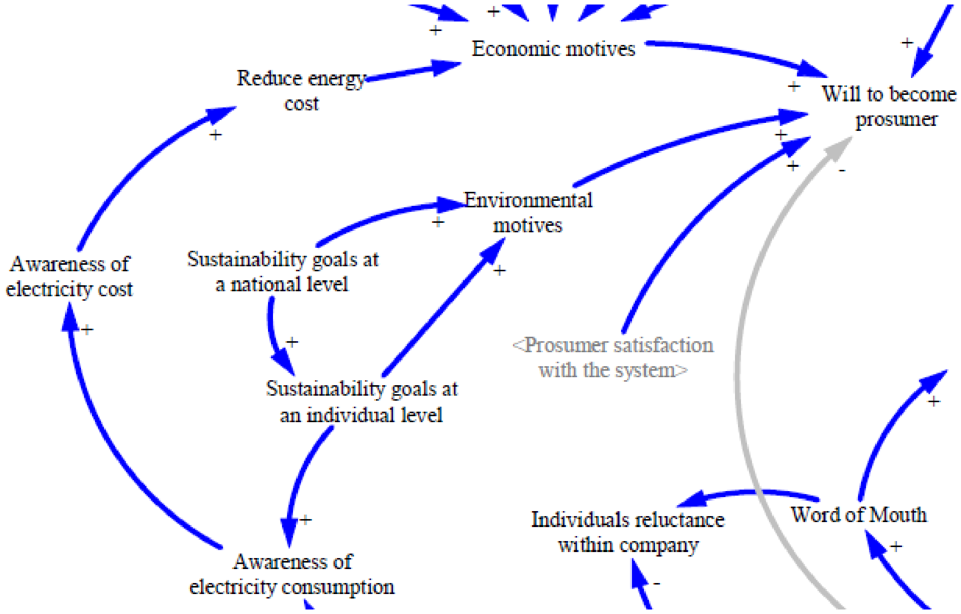

Figure 5.3: Environmental motivations

Moreover, the **Sustainability goals at an individual level** increase the **Awareness of electricity consumption**, which in turn leads to a higher will to **Reduce energy cost**. Through this connection, environmental motives connect with economic motives, as it is shown in Figure 5.3.

Energy cost reduction is probably the most important motive of all. **Economic motives** play a key role as companies ultimate goal in adopting solar is, in most cases, reducing costs. Other economic motivations for prosumers are the **Subsidies**, the **Uncertainty of future cost of electricity**, **Tax reduction** and the **Drop in price of PV panels**. A thorough explanation on the nature of each of the motives is presented in Section 4.

Instrumental motives are also considered drivers for adoption. Amongst them, the will to **Produce own energy** has emerged to be crucial. **Contribute to the local energy system** has also been found relevant, together with the **Diversification**, as a way of broadening the commercial activities of the company and the will to **Upgrade conditions for customer** in order to give customers an upgrade in their energy system, which in the end will create a higher loyalty and benefit the company.

Figure 5.5 shows both the **Instrumental motives** and **Symbolic motives**. **Symbolic motives** are **Branding motives** and the **Will for self-sufficiency**.

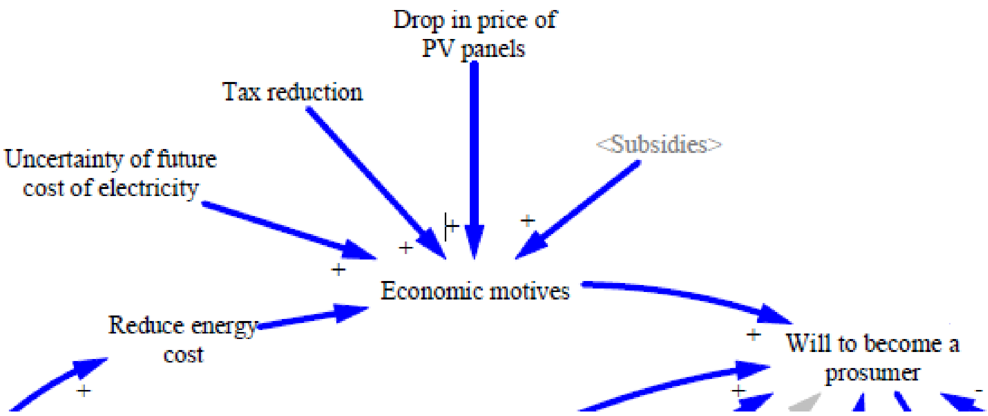

Figure 5.4: Economic motivations

The latter is of great importance for the future of the energy market. Not only it increases the interest in adopting solar, but it is also considered one of the consequences of owning the panels, and a driver for the adoption of battery storage systems. Prosumers gain a higher degree of autonomy from utilities and energy companies, what triggers a desire for even more self-sufficiency.

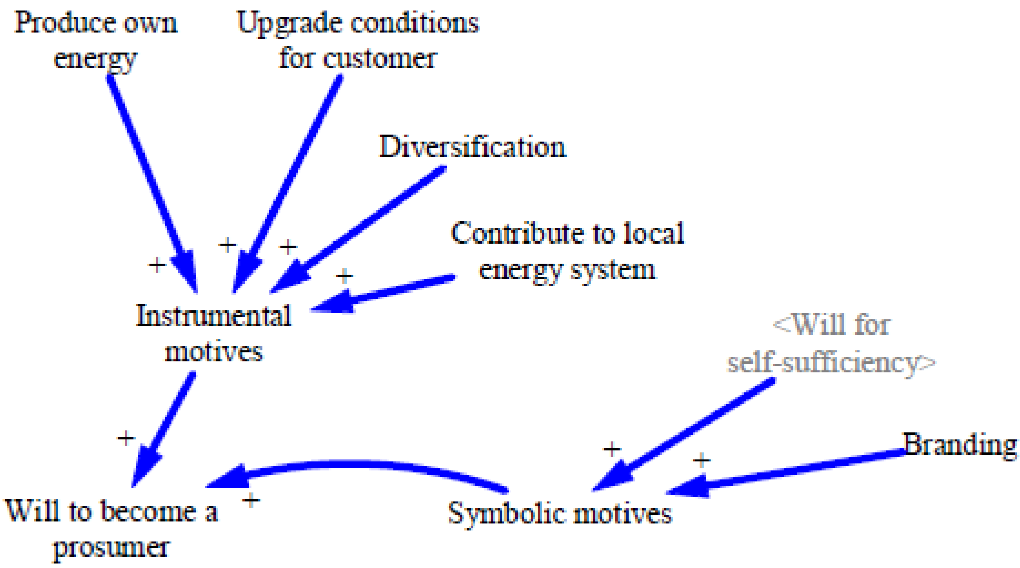

Figure 5.5: Instrumental and Symbolic motivations

On the other hand are the **Barriers**. These represent those factors that slow down the deployment of solar either by imposing delays in the process of adoption or by directly leading to giving up on the project. **Barriers** of different natures have become apparent throughout the development of this project, with special relevance the ones based on economic factors, those based on personal values and those determined by the legislation framework.

As an example of a value-based barrier, the **Individuals reluctance within the**

company which addresses the opposition to the adoption of prosumerism presented by some of the employees inside the prosumer company causing a delay in the development of the project for years. This variable is decreased by the **Word of mouth** factor and the **Induced innovativeness** which is considered to engage employees in the energy-related activities of the company. Another non-economic barrier is the **Conflicts between actors**, representing the disputes happening between prosumers, installers and utilities. As what refers to economic hurdles, the **Investment cost**, which is decremented by the **Subsidies**, and the **Lack of compensation for fed-back electricity** became clear after the interviews. Other relevant impediments for solar deployment are the **Legislation barriers**. The lack of a supportive legislation framework plays a key role as it limits the possibilities for prosumers, decreasing the attractiveness of the investment.

From a model perspective, these variables have been considered to have an effect on both the **Will to become a prosumer** and the **Likelihood to become a prosumer**, depending on whether they influence the perception of prosumers before or after gathering information on the investment. **Barriers** are shown in Figure 5.6.

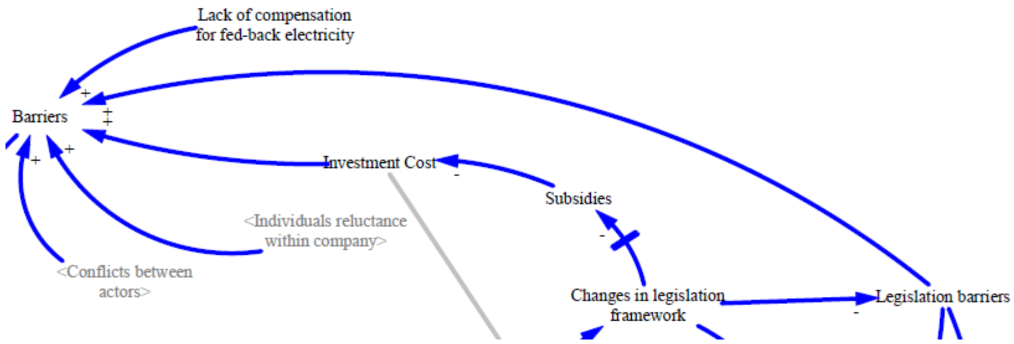

Figure 5.6: Barriers

Once barriers have been overcome, the potential adopter becomes a **Prosumer**. Becoming a prosumer is a driver for certain behaviours. Owning PV panels generates a feeling of **Induced innovativeness** among prosumers. This, contributes to an increased **Prosumer engagement in the local electricity system** which in turn increases the **Awareness of electricity consumption**. Besides that, it has been shown that enrolling in prosumerism also induces a higher **Will for self-sufficiency** and prompts the **Decentralisation of production**. Additionally, prosumerism increases **Customer satisfaction**, what in turn leads to a higher **Customer engagement in the local electricity system**.

Both the **Customer engagement in the local electricity system** and the **Prosumer engagement in the local electricity system** promote the **Cooperation between actors**. The latter is also benefited by the **Will to become a prosumer** and induces a greater **Likelihood to become a prosumer**. This bidirectional connection represents that cooperation is an important factor for promoting the installation of the panels and is also prompted by installing them.

Cooperation between actors reduces, and is reduced, by the **Conflicts between actors**. The **Conflicts between actors** have two dimensions. An economic dimension represented by the **Economic conflicts** variable, addresses the disputes regarding installation costs between actors. The social dimension, represented by the **Social conflicts** variable, is referred to the disagreements between prosumer and other agents. As an example, conflicts between companies and customer arise in matters such as the ownership of the panels. Both dimensions of the problem are affected by the way the **Benefits sharing** is arranged. Alternatively, the **Share of investment cost** exclusively has an impact on the **Economic conflicts**.

The **Prosumer business model** is what determines the way the benefits are distributed and how the investment is payed for. The business model is influenced by the decisions of different stakeholders, i.e, **Utilities decisions**, **Real Estate owners decisions** and **Housing companies decisions**.

Two other variables have been considered to influence the **Prosumer business model**. The **Cooperation between actors** is fundamental for the prosumers to decide what type of model they want to deploy in their building. On the other hand, **Economic savings** are important to ensure the viability of the model.

Together with the **Economic savings**, the **Customer satisfaction** affect the **Prosumers satisfaction with the system**. This feeling promotes in prosumers a higher **Will to become a prosumer** again.

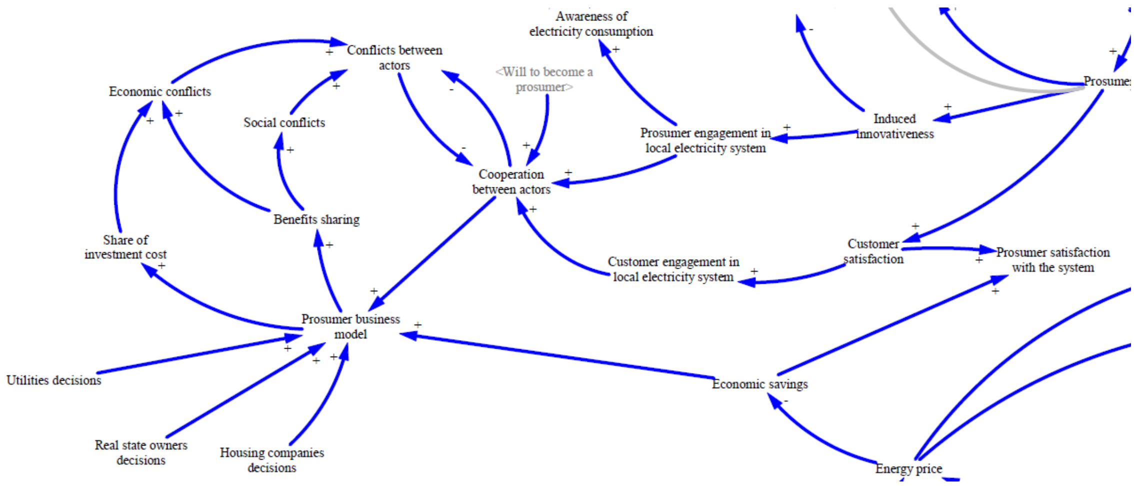

Figure 5.7: Prosumers business model

The variable **Decentralisation of production** represents the impact of prosumerism in the energy market. A new **Prosumer** goes towards the **Decentralisation of production**. As a consequence, this will induce **Changes in the legislation framework** in a near future, which cannot be quantified, hence the delay in the relation between variables. These regulation changes will contribute to the gradual depletion of the **Legislation barriers** that currently constrain the emergence of **Innovative business solutions for prosumers**. Moreover, the trend in the past years leads to the assumption that additional **Changes in the legislation framework** will eventually reduce the **Subsidies** for new installations.

Innovative business solutions for prosumers will increase the **Likelihood to become a prosumer**, and in consequence, the number of **Prosumers** increasing even more the **Decentralisation of production**. The effect created by this reinforcing loop is one of the biggest challenges that retailers and utilities will face with the uptake of decentralised generation.

New financial models for prosumers will also provide a gateway for the use of battery storage systems and other appliances. As **Legislation barriers** disappear, and **Innovative business solutions** arise, the interest in storage systems will grow. As a consequence, the **Likelihood of adopting BSS** by PV owners will be higher, positively influenced by factors such as the **Decrease in prices** or the **Will for self-sufficiency**.

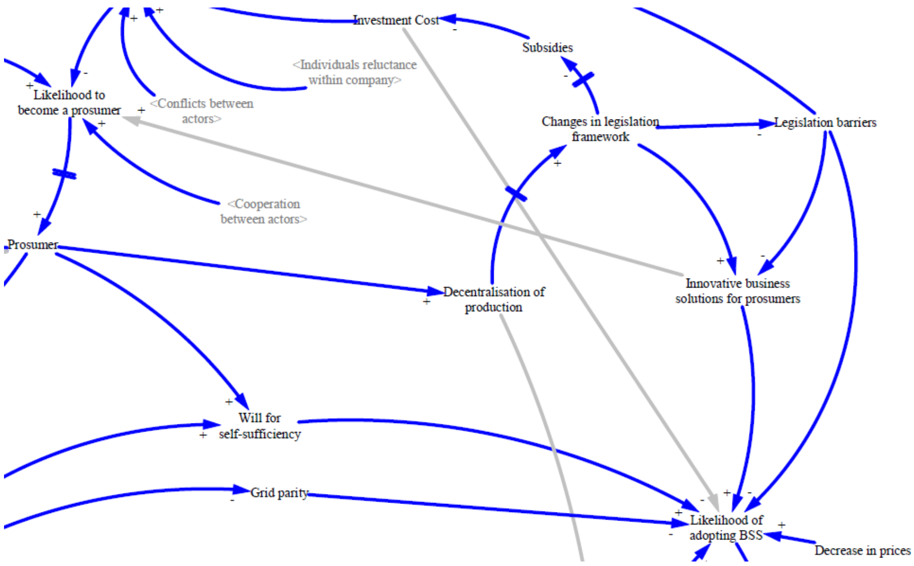

Figure 5.8: Future changes induced by an uptake of prosumerism

Currently, some barriers affect the deployment of storage systems. Barriers to the **Likelihood of adopting BSS** are the **Legislation barriers**, the high **Investment Cost** and **Grid parity**. The latter is considered to also have an inversely proportional effect on the **Will to become a prosumer**. The **Likelihood of adopting BSS** contributes at the same time to the number of **Prosumers with PV & BSS**.

The deployment of storage systems can have a positive and negative impact in the **Viability of utilities business model**. On the one hand, fluctuations in demand and their effect on the network can be controlled in a more efficient way. A higher number of **Prosumers with PV & BSS** reduces the individual **Prosumers impact on the grid** with the consequent reduction in **Grid technical issues**. The latter is also affected by an increased **Decentralisation of production**, which induces a larger number of **Grid technical issues** due to the large amounts of electricity put into the grid in times when production rates are high like the summer.

Grid technical issues increment the **Utilities cost**, which could be reduced through the use of **Smart grid appliances**. Higher costs stagger the **Viability of utilities business model**. Consequently, since batteries reduce the **Utilities costs**, embracing storage systems can help increase the **Viability of utilities business model**.

On the other hand, more batteries reduce **Grid consumption**. The latter is also decreased by the uptake in the number of **Prosumers**. Reduced demand reduces the intake from the variable price of utilities, and therefore the **Utilities revenue**. If grid owners revenue streams are cut down, the **Viability of the utilities business model** is put at risk and generates the need for a higher **Grid price** to ensure the feasibility of the network. On the contrary, if the **Viability of utilities business model** is increased, the **Grid price** is decreased.

From a behavioral perspective, fluctuations in **Grid price** impulse the **Changing role of utilities**. If the role of utilities is changed, then an increase of **Innovative business solutions for utilities** will necessarily arise, augmenting the **Viability of utilities business model**. However, **Innovative business solutions for utilities** are restricted by the **Legislation barriers** through the Electricity Act and by the **Lack of incentives for utilities**. At the same time, the **Viability of utilities business model** decreases the appraisal of **Innovative business solutions for utilities**.

As this conceptual model targets the dynamics of prosumer buildings, usually the spare energy that is fed back into the grid is relatively small, and exclusively occurs in times of high production and low consumption, like the summer. Therefore, **Retailers price** is not affected by it, as it is in the case of households. **Retailers price** does however affect the **Energy price**, so in this point households dynamics connect with prosumer buildings dynamics.

All in all, **Energy price** is a combination of the **Retailers price** and the **Grid price**. An increase on any of these two, increases the **Energy price**.

Energy price lessens **Grid parity**, which, as said before, decreases the **Likelihood of adopting BSS** and the **Likelihood to become a prosumer**. Less **Grid parity** means more chance to engage in prosumerism, and therefore more **Prosumers**. In consequence, **Grid consumption** is reduce even more. This loop with a reinforcing

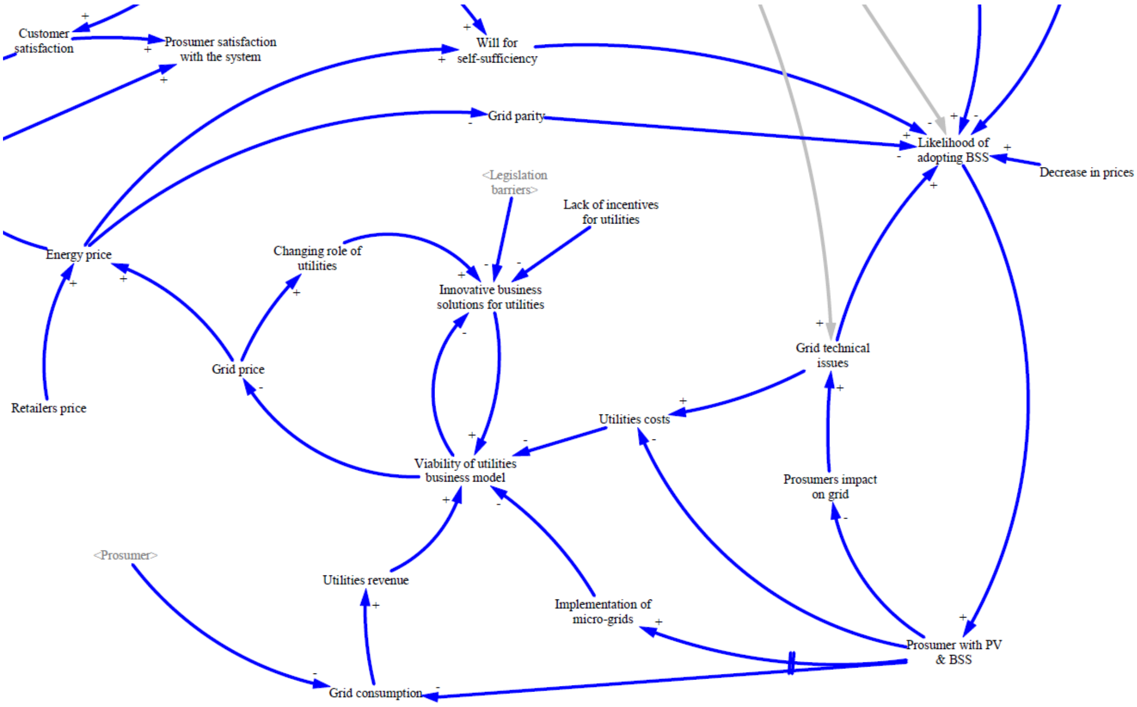

Figure 5.9: Utilities dynamics

nature is known as the Utility Death Spiral.

Higher **Energy price** conducts to a higher **Will for self-sufficiency** in prosumers, with the previously mentioned consequences that this has. In addition, **Energy price** reduces the **Economic savings** from installing the panels.

Finally, microgrid adoption is considered in the model as a possibility for a future energy scenario. **Prosumers with PV & BSS** will potentially increase the **Implementation of micro-grids** putting at risk the **Viability of utilities business model**.

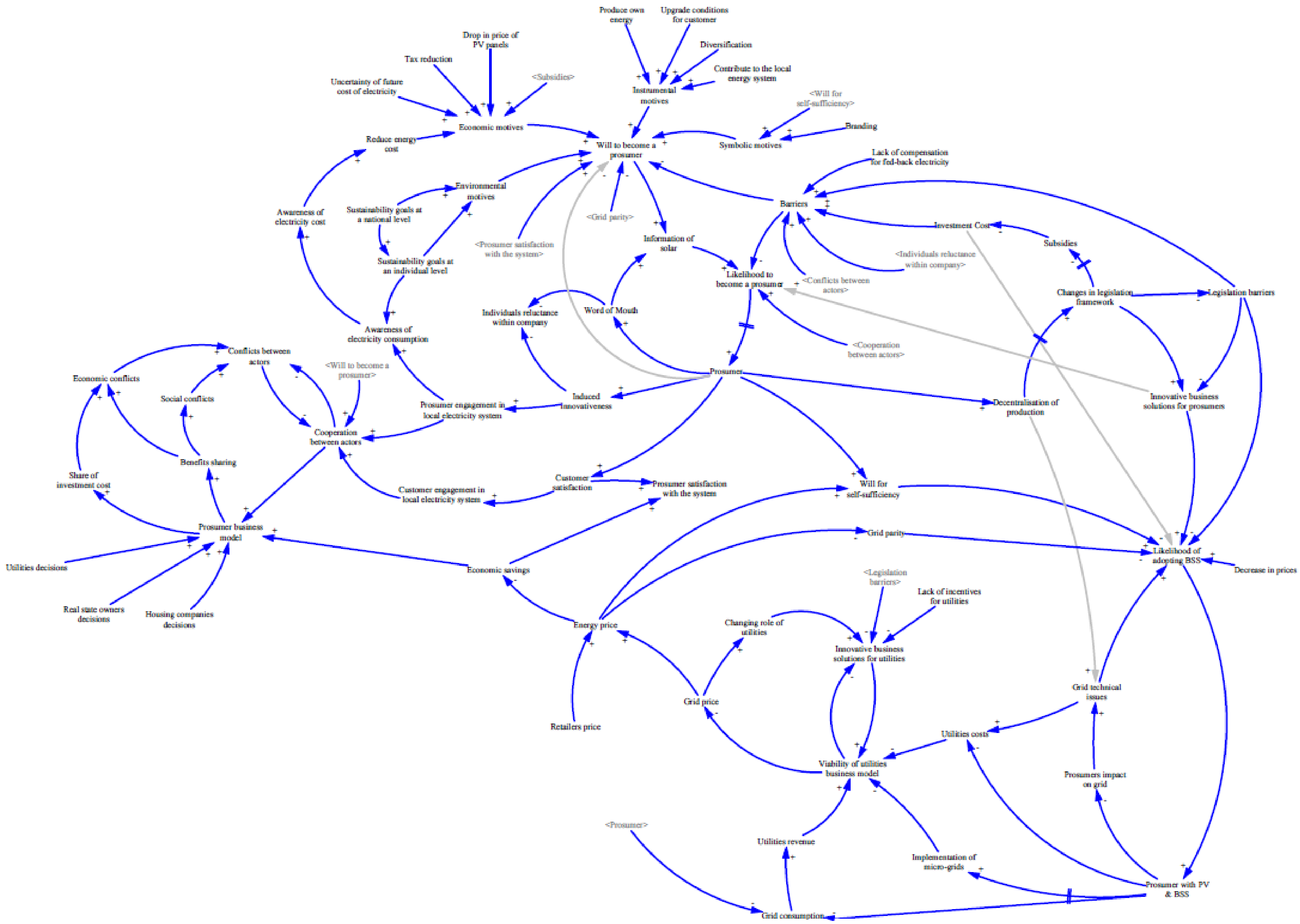

Figure 5.10: CLD of Prosumerism in Buildings

5.2 Stock and Flow Diagram

5.2.1 Previous Considerations

The SFD combines economic and behavioral aspects, with the complications inherent to addressing the relation between these types of variables. On top of this, units have had to be adjusted to ensure obtaining reliable results. Merging both dimensions has not been straightforward. As a result, certain flaws in unit assessment are present, which have been resolved by adding auxiliary variables to ensure unit consistency.

The economic factors, quantifiable and concrete, depend on assumptions based on available data from public resources accessible to the general public, and first-hand data obtained from the peers participating in the interviews. The assumptions made to develop the system are presented now:

- The initial investment cost per capacity does not include the Value-added tax (VAT).
- Panels do not degrade over their lifetime.
- The spot price per energy unit of electricity for companies is approximately 66% of one unit of electricity.
- There are no additional costs in the system rather than the investment cost.
- The subsidies are included int the LCOE.
- An average of 10% of the output of the panels is stored in batteries.
- The number of buildings following the prosumer scheme has been calculated according to the data provided by [Lindahl et al., 2018]. The number of current buildings has been found to be of around 1288, with a 150 kWp average capacity per building.

5.2.2 Model Development

A first part is displayed in Figure 5.11, where the factors that affect the rate of adoption of prosumerism are grouped, i.e., prosumers motivations and barriers. For simplicity, only economic barriers have been incorporated in the model. All the motives and barriers which were used to develop the SFD can be observed in section 4.

The **Motives to adopt solar PV** encapsulates all the motivations which do not have an economic nature, i.e., instrumental, symbolic and environmental. This variable is defined as the product of the **Factor to normalize motives to adopt** with the **Motives to adopt switch**. Motives can exist or not, and this is what the latter variable represents, either by having a 1 (motives exist) or a 0(motives do not exist).

Consequently, the **Motives to adopt solar PV** increments the **Likelihood to become a prosumer**, together with the product of the **Word of mouth factor** and the **Normalization factor for word of mouth**, and the product of the **Economic reality of solar PV** and the **Correlation factor of the likelihood to adopt prosumerism with the economic reality**.

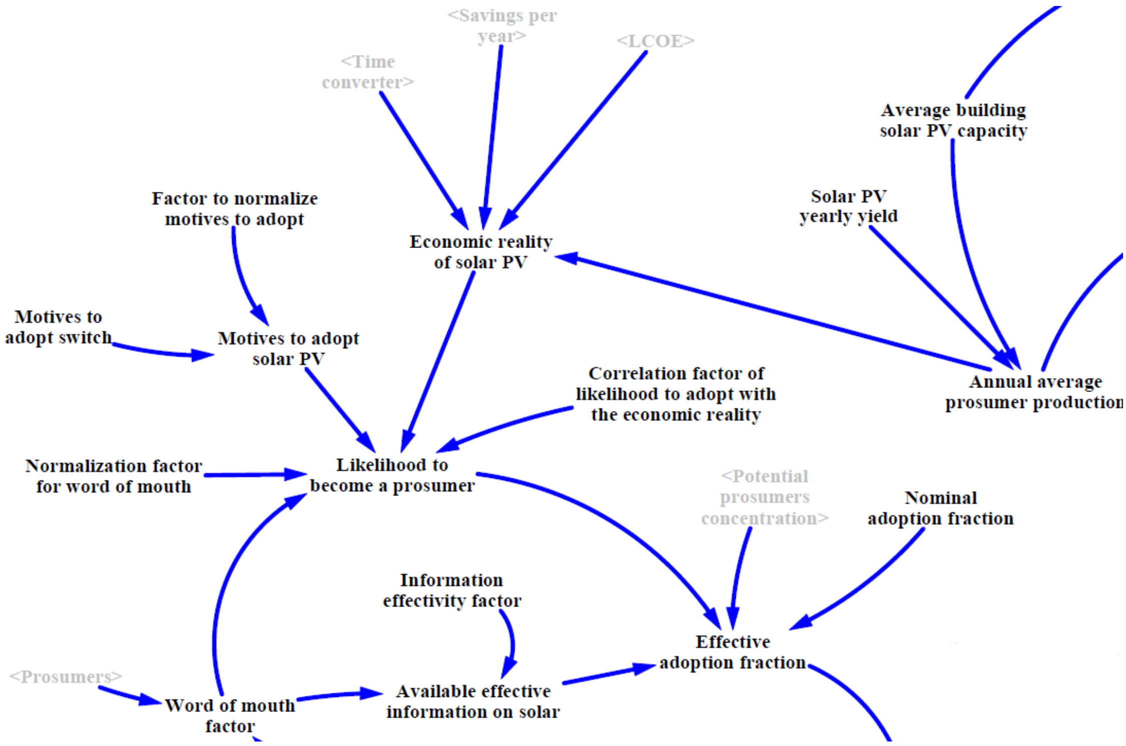

Figure 5.11: Factors affecting the likelihood to adopt prosumerism

At the same time, the **Economic reality of solar PV** is determined by the **Savings per year** minus the total annual cost of producing the electricity, given by the multiplication of the **LCOE** and the **Annual average prosumer production**. These variables will be explained later on this section with the rest of the economic factors.

The **Word of mouth factor** accounts for the information transferred from satisfied prosumers to potential adopters. It has been defined as the relative rate of **Prosumers** over the sum of **Prosumers** and **Potential adopters**. Each additional prosumer increases this ratio, as it is assumed that the information provided by that prosumer will increase the likelihood to adopt in potential adopters.

The product of the **Word of mouth** and the **Information effectivity factor** provides the **Available effective information on solar**. Subsequently, the amplification of the latter with the **Potential prosumers concentration**, summed to the **Likelihood to become a prosumer** and the **Nominal adoption fraction** result in the **Effective adoption fraction**.

The product of the **Effective adoption fraction** and the **Nominal contact rate** contributes to the **Adoption rate**. The **Nominal contact rate** is calculated as the product of the number of **Prosumers**, the **Potential prosumers concentration** and a **Time converter** for unit consistency. Alternatively, the **Potential prosumers concentration** is the ratio of **Potential adopters of PV** over the sum of **Prosumers** and **Potential adopters of PV**.

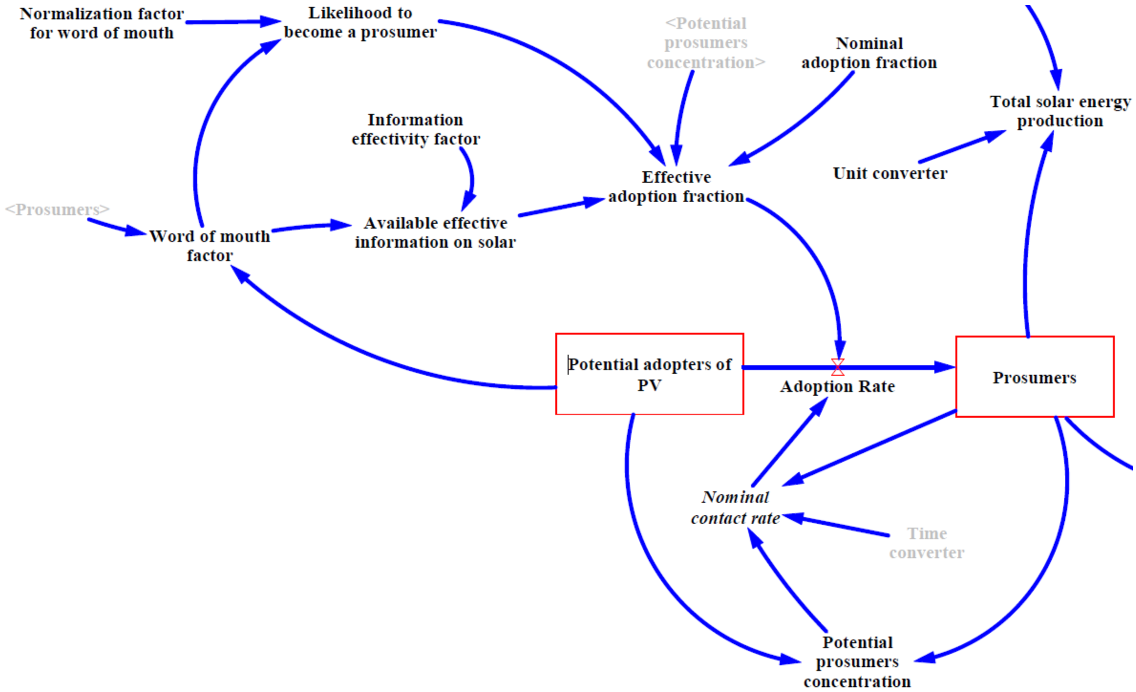

Figure 5.12: Potential adopters to prosumers flow

As shown in Figure 5.12, the flow from **Potential adopters of PV** to **Prosumers** is governed by the **Adoption rate**. Each of the two stocks has an preset value which significantly affects the outcome of the system. The initial values assigned to the buffers have been estimated through calculations based on current data of the total installed capacity in commercial buildings in Sweden.

The number of **Prosumers** in the market is a determinant factor for the dynamics of the solar market. A higher number of micro-producers will increase the yearly **Total solar energy production** together with the **Annual average prosumer production** and a **Unit converter**. This will in turn contribute to less **Grid consumption**, modelled as a function of the **Net energy annual consumption** minus the **Total solar energy production**.

In the first stages of model development, **Grid consumption** was directly linked to the **Electricity price**. Finally, due to the complexity enclosed in quantifying this relation, the connection was been removed.

The **Annual average prosumer production** is defined as the product of the **Solar PV yearly yield** and the **Average building solar PV capacity**. The **Annual average prosumer production** is linked to the levelized cost of electricity as it will be explained now.

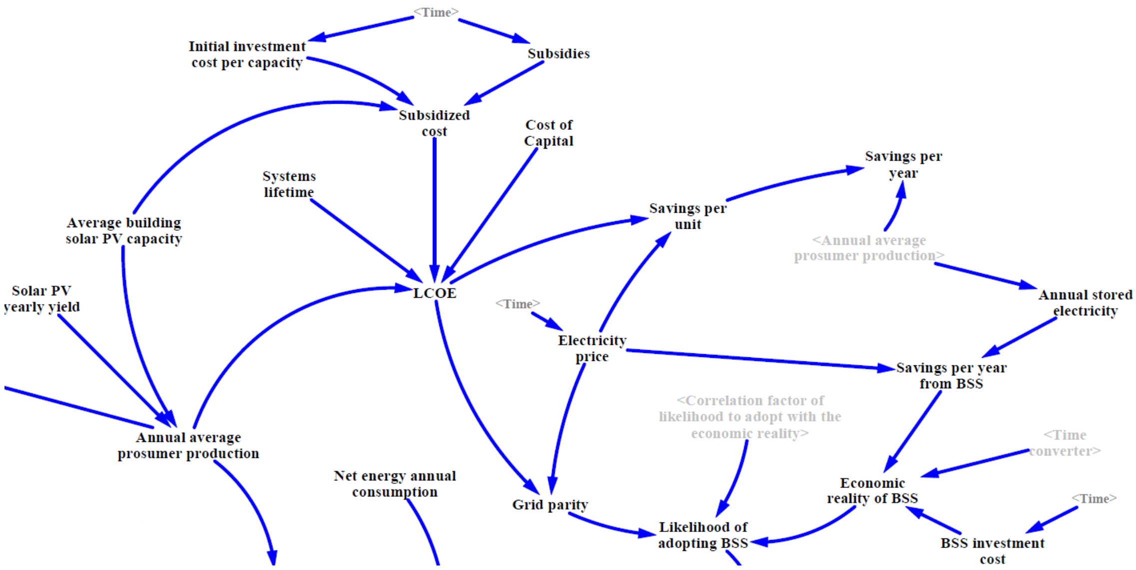

Figure 5.13: Economics of SFD

The **LCOE** is calculated as the **Subsidized cost** weighted with the **Cost of capital**, which represents the time value of money, and divided by the product of the **Annual average prosumer production** and the **Systems lifetime**. Alternatively, the **Subsidized cost** is the correspondent weighted value of the product of the **Initial investment cost per capacity** and the **Average building solar PV capacity** with th **Subsidies**. Both variables are defined as **Time** dependent.

The **LCOE** subtracted to the **Electricity price** provides the **Savings per unit**, which in turn, together with the **Annual average prosumer production**, contributes to the **Savings per year**. The annual savings determines the money saved by an arbitrary prosumer from adopting the panels versus not adopting. The ratio between the **LCOE** and the **Electricity price** outputs **Grid parity**, considered to be one of the key factors for the deployment of battery storage systems. In this variable, economic matters merge with behavioral aspects. This relation is outlined to accurately expose the influence of price fluctuations in prosumers perception of the usefulness of batteries. **Grid parity** also has an effect on potential adopters of PV systems, but this is considered to be included in the **Motives to adopt solar PV**.

Several other factors affect the diffusion of storage systems. In an attempt to reduce complexity, only economic factors and the mentioned **Grid parity** have been considered as influential factors. Thus, the **Likelihood of adopting BSS** is modelled as the rate between the **Economic reality of BSS** multiplied by the **Correlation factor of likelihood to adopt with the economic reality** and the **Grid parity**, as shown in Figure 5.13.

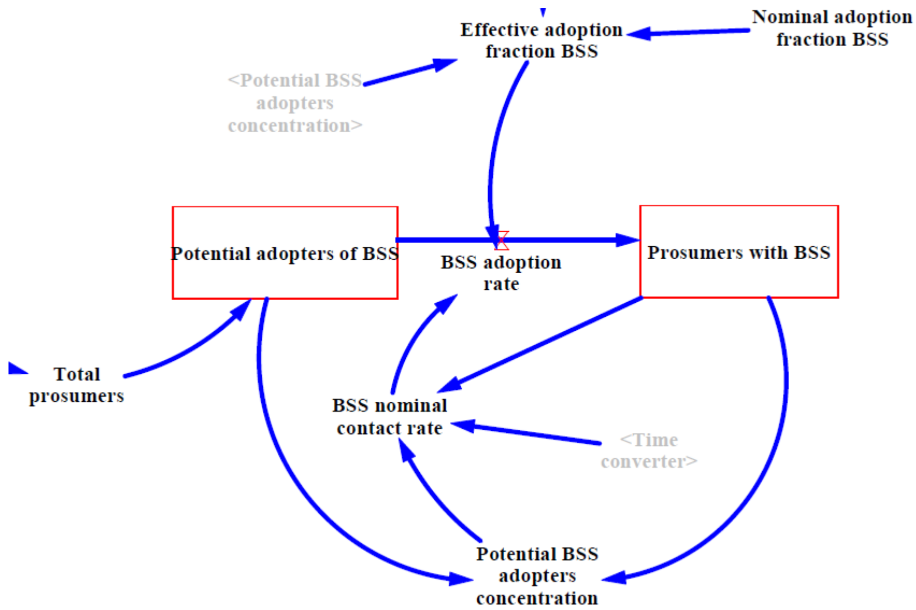

Figure 5.14: Battery dynamics of SFD

The **Economic reality of BSS** is calculated as the **Savings per year from BSS** divided by a **Time converter** and added to the annualised **BSS investment cost**. The **Savings per year from BSS** are not straightforward to calculate, and have been assumed to be the **Annual stored electricity** multiplied by the difference between the **Electricity price** and the spot price of electricity (considered as 66% of the electricity price). The **Annual stored electricity** is at the same time defined as 10% of the **Annual average prosumer production**. On the other side, **BSS investment cost** has been defined as a time dependent variable, according to a predefined set of values specified in Appendix A.

Subsequently, the **Likelihood of adopting BSS** increases the **Effective adoption fraction** together with the **Nominal adoption fraction of BSS** and the **Potential BSS adopters concentration**. At the same time, the **Potential BSS adopters concentration**, calculated as the rate of **Potential adopters of BSS** over the total of **Potential adopters of BSS** and **Prosumers with BSS**, contributes to the **BSS nominal contact rate**, multiplied with the number of **Prosumers with BSS** and a **Time converter**.

The product between the **Effective adoption fraction** and the **BSS nominal contact rate** determines the **BSS adoption rate**. The **BSS adoption rate** outflows the **Potential adopters of BSS** and inflows them into the **Prosumers with BSS** stock. The **Potential adopters of BSS** are initially modelled as the **Total prosumers**, meaning that only those consumers who have adopted solar panels are eligible to adopt batteries.

The final model can be observed in Figure 5.15. The results and conclusions derived from the simulations are displayed in section 6.

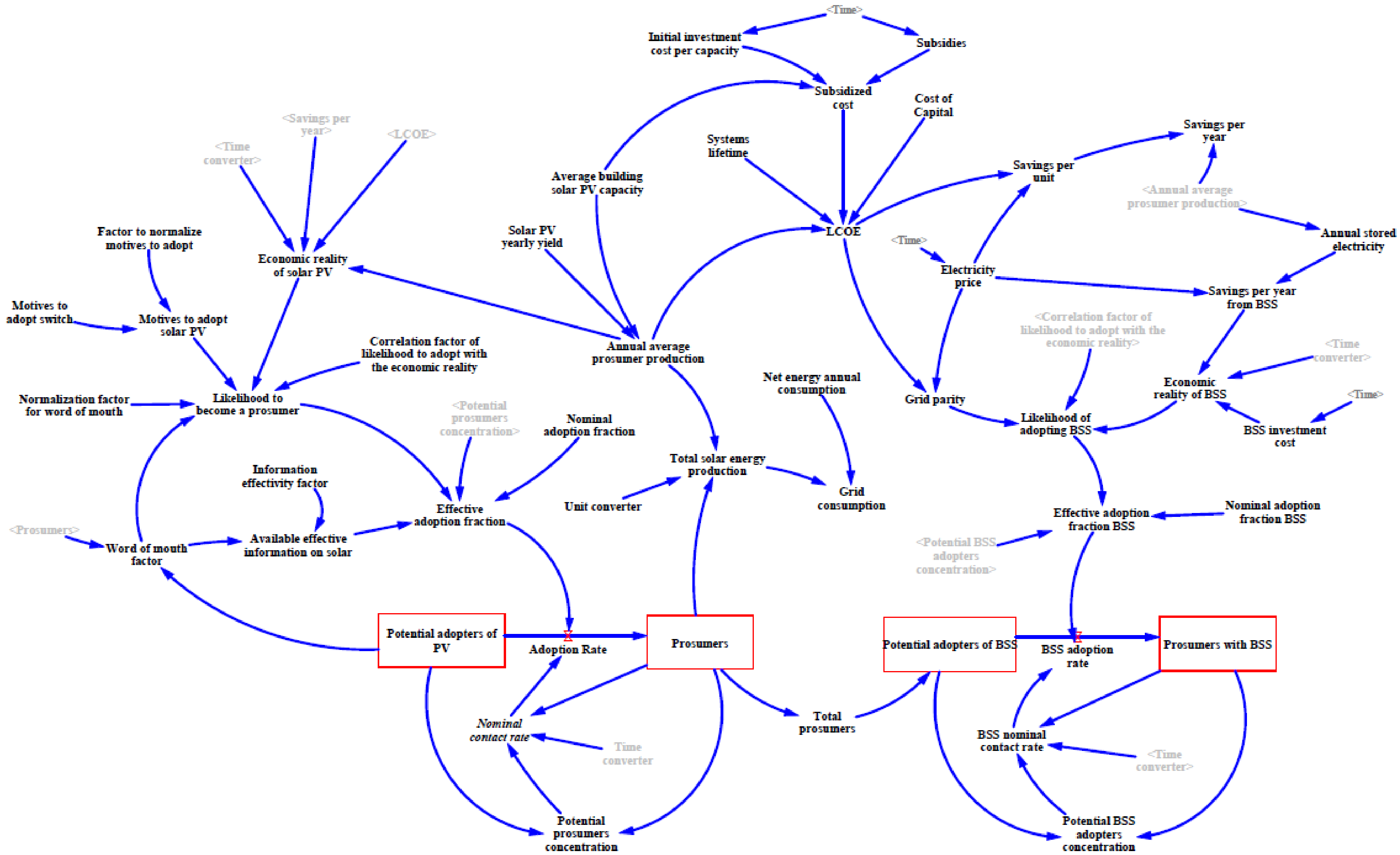

Figure 5.15: Final SFD Model

6
Results

This section presents the results obtained through the development of the models and the business analysis.

6.1 Findings from the conceptual model

The Causal Loop Diagram has provided a graphical way to present all the factors extracted from the interviews (see Section 4) and those which were found by previous research (see Section 2.1) and did not emerge in the interviews. In this way, it has been possible to connect the different aspects that affect prosumerism to observe how they are interrelated, and acknowledge how the motives and barriers are affected by decisions taken today, and how future resolutions will have an impact on the overall system.

One of the reasons for investing in solar PV technology that was not explicitly mentioned by any of the companies in the interviews, but was extracted from the research process, is the diversification of the economic activities of the company. Some companies become micro-producers as a way of broadening their business activities and exploring new ways of increasing their profitability. This is considered as an instrumental motive, and thus included in the model together with the other motives in this group.

The cooperation between actors has also been found to be important. This cooperation has different dimensions. One of them is the relation between prosumer and utility company. Another is the relation between prosumer and customer. Both dimensions induce the same effect, a higher cooperation translates into a more fluent communication, and vice versa, resulting in a better relation between agents. This makes it easier to reach agreements that improve the experience and hence the overall satisfaction with the system. Better communication is also important to engage the potential prosumer in order to facilitate the integration of these adopters into the system.

Another important factor, which links the price of electricity to the willingness of potential adopters to adopt, is Grid Parity. Grid Parity, is considered as a catalyst of Renewable Energy Technologies (RETs), since the investment becomes attractive in the eyes of the public. In the model it is accounted how Grid Parity not only affects the perception of the investment in the PV system, but also the perception of battery systems.

The legislation changes that will likely happen in a near future, needed to integrate all the technologies and facilitate the expansion of prosumerism have arisen as liberating factors for new business solutions, both for prosumers and utility companies. For the latter, a least restrictive legislation framework would enable new ways to develop alternative business models and explore new revenue streams.

However, as it is modelled, these changes will grant the possibility for potential adopters to embrace new more cost-beneficial models, which in turn would allure more customers and increase the rates of adoption of batteries.

This situation can affect the price of electricity in two ways. An increase in the number of prosumers would reduce the consumption from the grid. At the same time, assuming the constraints imposed by current governmental policies would be depleted, prosumers would be able to produce much more electricity in their installations, and then batteries would be seen as a worthy investment. At the same time, more prosumers would come into the system. In both cases, grid consumption would decrease, affecting utilities revenue and leading to an increase in the price of grid electricity.

From the utilities perspective, this situation would pose serious problems on their financial model, entirely based on estimations of electricity consumption. Should the consumption reduce drastically, the only way for them to ensure the viability of their business model would be to rise their price.

Furthermore, represented in the model are the higher utilities costs induced by an uptake of distributed generation and their consequences on the rest of the stakeholders of the system.

6.2 Simulation Results

The results from the simulations will now be presented.

As mentioned previously, the intended purpose with modelling the Stock and Flow diagram has been to observe the impact that potential changes in certain variables would have in the diffusion of solar PV adoption. In consequence, some parameters have been modelled as variant and others as constant over the course of the simulations. The latter can be observed in Appendix A. The changing variables will be explained further in this section.

For both types of variables, assumptions and calculations have been made. These approximations are based in current data obtained from reliable sources.

In the case of the number of new micro-producers, this number is heavily reliant on the initial number of prosumers and the number of potential adopters. For this model, the initial value of prosumers has been set to 1288, calculated through the ratio of the total capacity of commercial PV systems installed in Sweden and the average capacity per installation obtained from [Lindahl et al., 2018]. The number of potential adopters has been set arbitrarily with a value considered within a viable range.

The same applies for storage systems. Due to the difficulty in determining the current number of non-individual prosumers owning storage systems in Sweden, a rough estimate based on the total storage capacity installed in the country has been made, delivering an approximate 50 prosumer buildings with batteries.

Several simulations have been performed on the basis of a sensitivity analysis. Those variant parameters of the model have been assigned different values in each case. As a result, each of the scenarios has delivered different estimations of how these changes could affect prosumerism.

The simulation time has been selected as 15 years, with a yearly resolution. The results for the simulations and the different case scenarios are presented now.

6.2.1 Case Scenarios

The price of electricity, the investment cost of PV technology and the subsidies granted for new installations have been tailored for each of the case scenarios. The previous findings from interviews and literature research, presented in sections 4 and 2.1 respectively, lead to the assumption that these parameters will suffer important changes in the coming years.

Another variable of the model which is likely to change is the price of storage systems. However, the dynamics of the cost of batteries is more uncertain and unclear than in the case of PV panels. For this reason, and to avoid additional complications in the model, batteries investment cost has been assumed to experience an approximate 15% decrease in the coming 15 years, remaining with the same value over the whole case scenarios.

Five case scenarios have been developed, presented in Table 6.1. In **Case 1**, following their respective trend in the past 5 years, the variant parameters have been modelled accordingly. For **Case 2**, subsidies have been removed, as it is a possibility that they will be depleted soon as the interest in PV technology rises. **Case 3** hypothesises with the price of PV panels will remaining constant. **Case 4** is opposite to the previous case, with the price of electricity remaining constant over the years, but with a decreasing price of PV technology. Finally, **Case 5** is a mix of the previous cases.

Cases	Variable	Assumptions
Case 1	Initial investment cost per capacity Electricity price Subsidies	10% reduction every 5 years 20% increase in 15 years Gradually depleted
Case 2	Initial investment cost per capacity Electricity price **Subsidies**	10% reduction every 5 years 20% increase in 15 years **No subsidies**
Case 3	**Initial investment cost per capacity** Electricity price Subsidies	**Constant over the years** 20% increase in 15 years Gradually depleted
Case 4	Initial investment cost per capacity **Electricity price** Subsidies	10% reduction every 5 years **Constant over the years** Gradually depleted
Case 5	**Initial investment cost per capacity** **Electricity price** **Subsidies**	**Constant over the years** 20% increase in 15 years **No subsidies**

Table 6.1: Case scenarios

6.2.2 Results from the SFD

As the resolution of the model is annual, the values hereby presented represent the factors which affect prosumers investing in that same year.

As the variant parameters are modelled to change every year, representing the mentioned potential changes, this affects those parameters of the model dependent of them. Specially relevant is the case of the levelized cost of electricity or LCOE, which accounts for the average revenue per unit needed to recover the capital cost and maintenance costs of operating a generating plant, in this case, PV panels.

In the model, every iteration of the model (every year) changes the LCOE, except when the subsidized cost remains constant. As a consequence, the LCOE is specific for each year, meaning that a prosumer investing in year x has a different LCOE than a prosumer investing in previous or future years. For that reason, the savings per year of that new adopter, calculated as the difference between the LCOE and the price of electricity, can only be observed for the year of the investment, as the next year in the simulation the LCOE will change induced by changes in the prices of the panels or the subsidies.

Should the LCOE remain constant over the entire simulation time, it would allow to observe the yearly savings per year of a prosumer investing in year x, contingent to the changes in the price of electricity. This case is represented by case 5. As the LCOE remains the same over the entire simulation, since the investment cost and the subsidies remain equal, the savings per year of a new prosumer adopting in year x are the same that a prosumer investing in previous year would have in year x. As the electricity price rises, the savings per year also rise, as it can be observed in Figure 6.1.

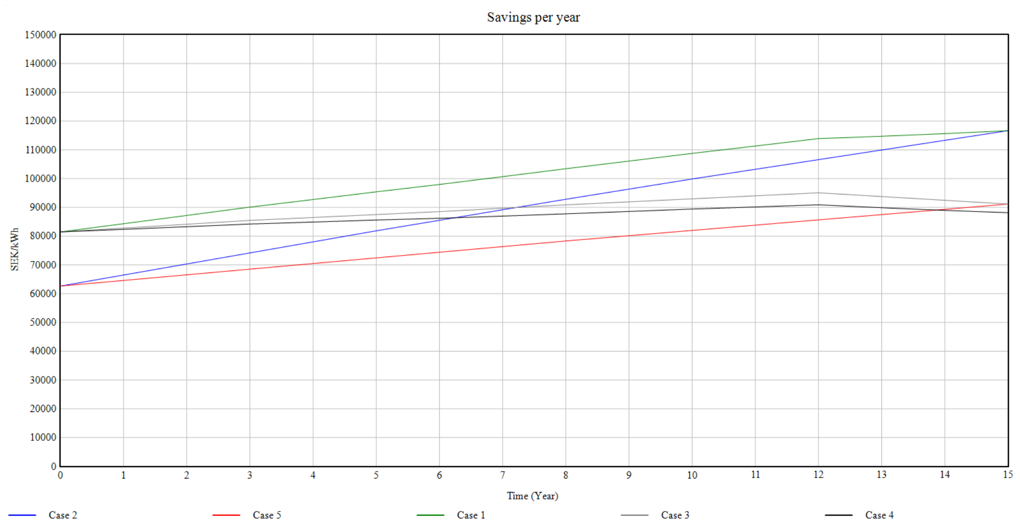

Figure 6.1: Savings per year for an arbitrary prosumer investing in year X

From the plot, it can be seen how case 1 is the one that brings the best conditions for new prosumers throughout the 15 years, whereas case 5 provides the worse. The latter and case 2 are the unsubsidised schemes, and therefore bring less benefits in the initial years where subsidies are still large in the other cases. From year 7, case 2 already provides better conditions than cases 3 and 4, induced by the reductions of PV prices and the rise of electricity. In consequence, by the end of the simulation, the second case brings the same savings per year to new prosumers as case 1.

In cases 1, 3 and 4, subsidies are 10% in year 12 for new adopters, but they are removed completely in year 15. Hence the decrease in the pattern of the savings.

For cases 3 and 4 this is significant, as it shows that new prosumers from year 12 will have less savings than the ones investing in previous years.

Some conclusions can be derived from these results. In the early years of the unsubsidised cases, the attractiveness of adopting solar PV is reduced in comparison with the subsidised cases. This would most likely result in less prosumers adopting solar PV, as the savings are less. However, in the long run, as subsidies would be depleted in all cases, the appeal of the investment would be determined by other factors.

The savings per year affect the perceived utility of prosumerism, and in consequence, the perception of potential adopters to invest modelled as the likelihood to become a prosumer. As mentioned, the cases where grants for new installations do not exist deploy a lessened interest in installing the panels. However, the likelihood also depends on other factors, such as the motives for adoption or the word of mouth, which are the ones represent in the model.

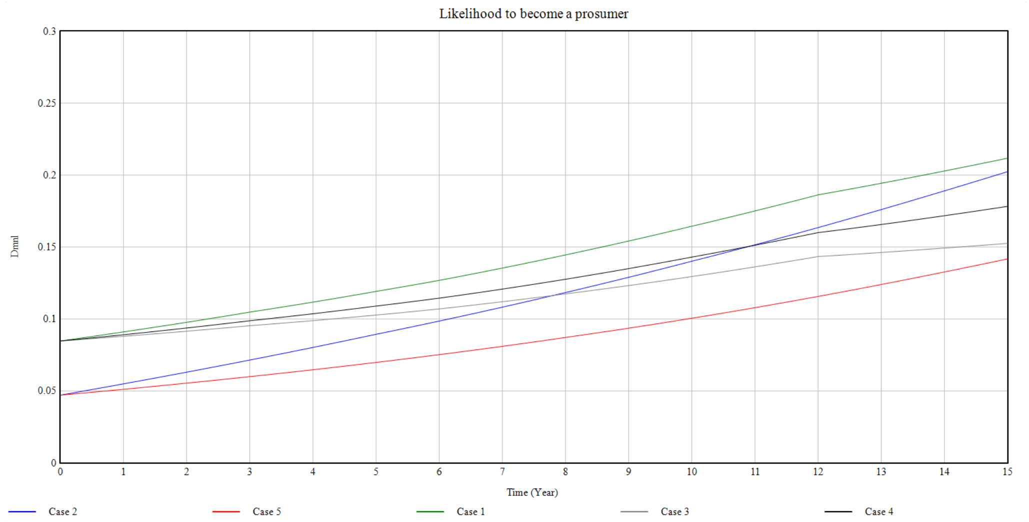

Figure 6.2: Likelihood to become a prosumer or attractiveness of the investment for potential adopters

As it can be observed in Figure 6.2, the cases with higher savings are those which induce a higher likelihood. The y-axis in this figure represents the dimensionless aspect of quantifying a likelihood. The likelihood increases throughout the simulations as a result of the increase in savings per year and the word of mouth factor. As the word of mouth depends on the number of current prosumers, the higher the number of prosumers is, the higher the likelihood.

The number of prosumers will then be higher for the first case, with a total of 5000 PV owners by that year. The lowest rates of adoption are shown in case 5, with almost 1000 prosumers less than in the previous case. For cases 2,3 and 4, the number of prosumers is similar.

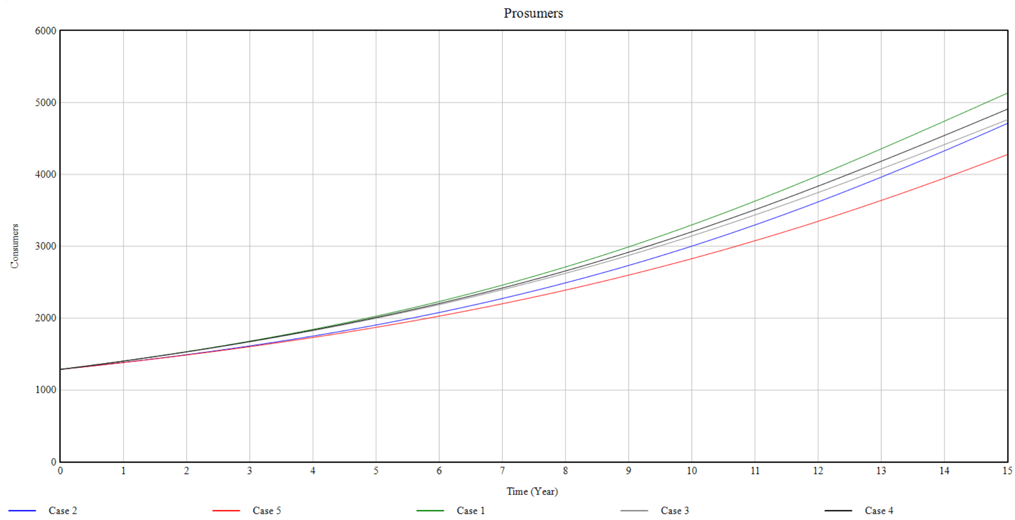

Figure 6.3: Evolution in the number of prosumers

Here, the inference of the number of prosumers is an approximate number and depends on several external factors which have been neglected due to the difficulty of quantifying them in the model. Therefore, the absolute values should be taken as rough estimations.

The number of prosumers is considered the number of potential battery adopters. To be able to include batteries in the model, a set of assumptions has been made, discussed in Section 5.2.1. Among them, the need to quantify the economic benefits provided by batteries, or the investment cost.

In the model, one of the motives for the adoption of batteries is Grid Parity. This factor has been modelled as the ratio between the LCOE and the price of electricity. Therefore, as it can be observed in Figure 6.4, the factor lowers when the LCOE becomes smaller. In most of the case scenarios, except when the LCOE and the price of electricity remain constant. As the LCOE becomes smaller, the likelihood of adopting BSS is increased. However, in the cases where subsidies are considered, there is an increase from year 12, induced by the complete depletion of subsidies, which in turn increase the LCOE in comparison to previous years.

Other factors that affect the likelihood to adopt batteries aside from grid parity, is the economic reality of batteries, determined by the investment cost and the savings per year. The economic reality is negative throughout the simulations, as batteries themselves do not provide any direct income to prosumers, only cost reductions which are not high enough to recover the investment in the system. Hence, the negative sign.

Therefore, the likelihood of adopting a battery will change inversely proportional to the grid parity shown above, as the economic reality remains somewhat constant

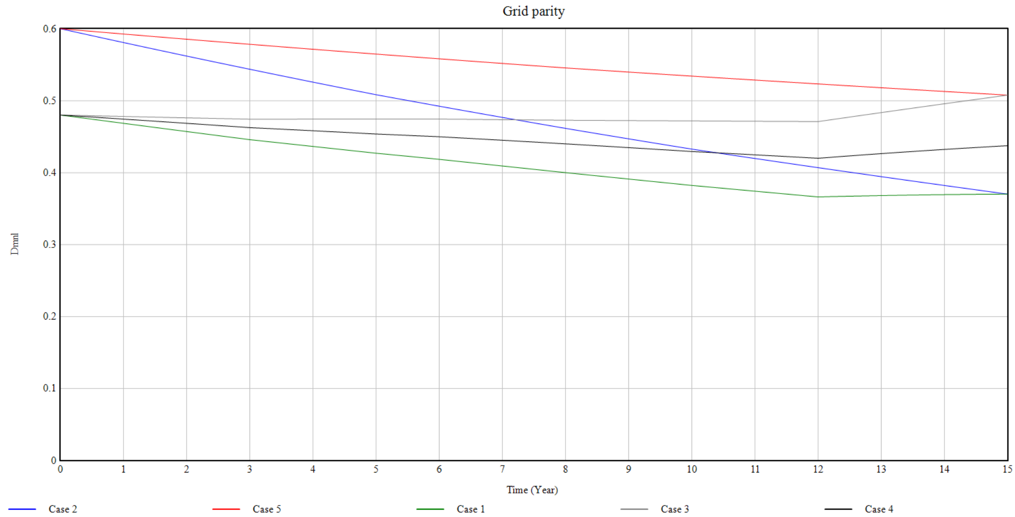

Figure 6.4: Ratio between the LCOE and the price of electricity over the years

over the whole simulation time. In consequence, the number of prosumers with BSS will slowly increase, as This is deployed in Figure 6.5.

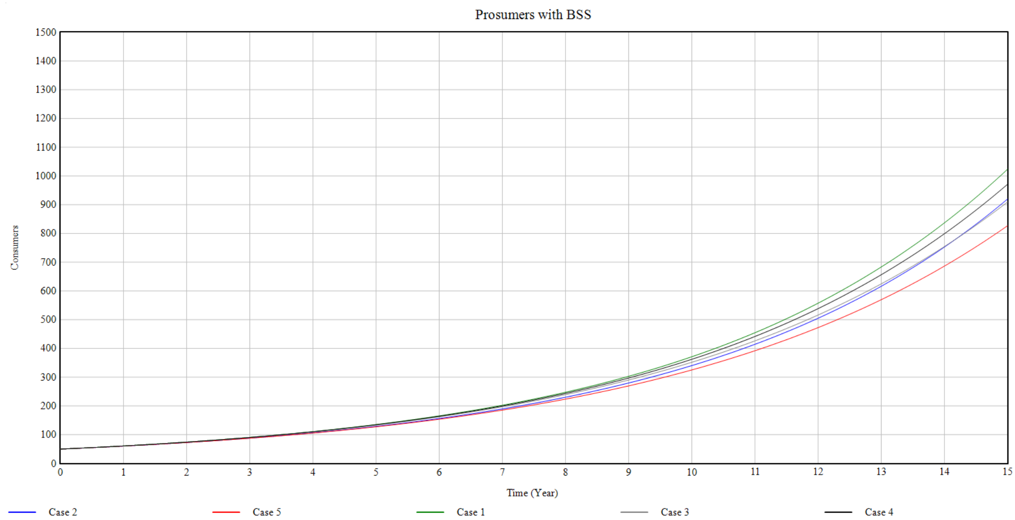

Figure 6.5: Evolution of the number of prosumers with BSS

Again, case 1 delivers the highest number of battery adopters on the basis of the results exposed above, reaching a peak of 1000 battery owners for after 15 years what translates in a 1500% increment with regards to the current value. Case 5, on the other hand, delivers the smallest number with a total of 800 battery adopters by the end of the simulation.

6.2.3 Business analysis

Besides the results obtained with the simulations, a business analysis with first hand data provided by the peers of our interviews has been implemented as a way to validate the results obtained from the simulations and estimate payback periods and profitability for different commercial installations.

Three different systems have been considered. The first two are based on real operating systems in the area of Västra Götaland. The third system is a fictional system created with the same data used in the SFD.

For the three cases, the data shown in table 6.2 has been used. The technical data particular to the systems and the results for the business analysis can be observed in table 6.3.

Assumptions	Value
Fractional First Year Yield	950 kWh/(kWp*Year)
Electricity Price	1.1 SEK/kWh
Systems Lifetime	30 Years
Degradation Rate	0.5
Interest Rate	2 %
Subsidies	20 %
O&M	10000 SEK

Table 6.2: Assumptions for the Business Analysis

	Parameters	**Prosumer 1**	**Prosumer 2**	**Prosumer 3**
Values	PV Capacity [kWp]	178	255	150
	PV Cost [MSEK]	2.9	4.2	1.605
	Battery Output [kWp]	96	-	-
	Battery Investment [MSEK]	1	-	-
	Agreement	PPA	PPA	PPA
Results	LCOE [SEK/kWh]	0.69	0.51	0.33
	Total Savings [SEK]	1892479	3825137	2938421
	SPP [Years]	19	14	10

Table 6.3: Business analysis results

As it emerges from the results presented above, including batteries in the installation as it is the case for "Prosumer 1", significantly increases the pay-off period of the system with respect to other installations which do not include the storage system such as "Prosumer 2". On top of this, the LCOE increases significantly, leading to less savings over the lifetime of the panels.

7

Discussion & Conclusions

This chapter discusses the findings from Section 6 and places them in context with the findings from the interviews presented in Section 4.

Besides, the conclusions and suggestions for future work for this Master Thesis are presented.

7.1 Discussion

Section 1.2.1 presented the main research questions to be investigated, mainly the motives and barriers that affect the deployment of prosumer business models for non-individual adopters in Sweden, and the drawbacks brought to these organisations by enrolling in prosumerism.

Previous research conducted by [Warneryd and Karltorp, 2020] revealed how the reasons for adopting solar PV power depend on the role of the prosumer. As it is the case for this thesis, only the factors affecting prosumer organisations have been analyzed. Even within these type of prosumers, their motivations to install solar panels differ slightly.

As [Bergek and Mignon, 2017] pointed out, non-individual prosumers have financial motivations as primary drivers, with access to a RES and branding motives as other important reasons. This has become clear when extracting and analyzing the data from interviews with different energy stakeholders, conducted through a mixed-methods approach. Financial motivations have emerged as decisive factors, with cost reductions as primary goals. Other motivations such as customer satisfaction, environmental concerns, contribution to the local energy system, self-sufficiency, becoming producers of renewable energy or the previously mentioned branding motives have become apparent through these meetings.

External factors such as the decrease of PV prices in the last years, have also been found to contribute to the will of prosumers to invest. PV panels have dropped over 80% in the past 15 years reducing significantly the cost of installing, revealed as one of the main barriers for PV deployment. In consequence, a wider range of companies can afford to enroll in prosumerism. The results obtained from the simulatable model prove how this aspect is determinant in the likelihood to adopt prosumerism for new adopters, as it reduces the cost of generating electricity, hence increasing the annual savings obtained from the system. In the simulation cases where the cost was maintained over the years, the number of prosumers after 15 years was significantly lower.

Governmental incentives are also fundamental for promoting PV diffusion. Economically, financial aid provided by the state in the form of subsidies for new installations reduces the initial amount of capital that companies need to allocate for the panels. However, companies claim that subsidies are not a decisive factor, since in most of the cases, they take from 1-2 years to be granted, and cover at most 20% of the investment cost. The results from the simulations indicated that the potential depletion of subsidies is less relevant for the overall financial viability of the system than changes in other external factors, such as a potential rise in the price of electricity.

Prosumer business models must be planned in the long term by companies to ensure the economic profitability of the investment. Payback periods usually range from 10-19 years for installations from 150-255 kWh, as it was proven with the results obtained from the business analysis (see Section 6.2.3). This, corresponds to what certain peers mentioned as a reasonable pay-off time for the investment, ranging from 15-20 years.

Therefore, as it is of now, the profitability of the business model is indeed guaranteed if cost control is planned correctly, as long as batteries are not included in the project. However, the conditions for prosumer organisations are not so alluring. The incentives that companies enjoy for feeding the electricity back into the grid are very restricted, preventing them from obtaining a revenue from selling their produced electricity. In most cases, the interviewees claimed to be pointless to sell any electricity, as the difference in price with the electricity bought is insignificant. On top of this, the consumption in their buildings is high enough not to overproduce.

This situation determines the utility of investing in battery storage systems and does not justify the investment in BSS. As [Ollas et al., 2018] concludes, currently in Sweden the difference between the purchased and sold electricity is too low. However, in a future energy mix with a higher share of renewable produced electricity, more price fluctuations could occur, and then batteries could be charged in times of generation curtailment and that stored electricity could later be used during times of higher electricity prices.

As it has emerged from the Causal Loop Diagram, Grid Parity is a very important factor for the perception of prosumerism and batteries. Grid Parity, which occurs when the LCOE is lower or equal to the price of electricity, has been acknowledged by several authors as a main driver for adoption [Bergek and Mignon, 2017, Kubli and Ulli-Beer, 2016]. Lowered generating costs make prosumers more likely to commit to a long term investment as it becomes more financially beneficial. In countries like Sweden where the price of electricity is relatively low this is really important. This can be observed in the Grid Parity graph (see Figure 6.4), where the case scenarios with lower LCOE prove to be those where the grid parity induces the highest likelihood to adopt batteries, and in turn where the number of potential battery adopters is higher.

7.2 Conclusion

Summarizing the research questions presented in Section 1.2.1, this project concludes the following:

- Financial incentives have emerged as the main motives for companies. Non-individual organisations that enroll in the solar PV market in Sweden do so with the primary goal of obtaining cost reductions in their buildings, as well as achieving a better cost control of the electricity system. Instrumental motivations such as producing their own renewable energy or upgrading the conditions for the customer have also become clear from the interviews. In addition, environmental motives, self-sufficiency and branding reasons complement the motives that have been acknowledged in this Thesis.

- Most of the companies agree that the inclusion of the panels has improved the overall welfare of the electricity installation, improved the relation with the customer, enhanced the relation with the local utility company and contributed to the engagement of the employees in the local electricity system. In turn, this facilitates the integration of panels in future projects.

- Despite the subsidies provided by the government, the high investment cost has been revealed as a major barrier for PV deployment. The long payback times, ranging from 10-20 years depending on the size of the installation, generate a degree of skepticism on potential adopters. Apart from that, the lack of incentives for selling the electricity produced or the absence of a supportive legislation framework for companies have been revealed as compelling barriers for PV deployment. Restrictions such as the cap of 255 kWh of maximum installed constraint the possibilities for enterprises owning buildings with large roofs. According to one of the peers interviewed, companies such as IKEA are really affected by this restriction, as they have enormous roofs which are currently being underused.

- The inclusion of batteries is not a viable investment as of today. Proven by the results obtained from the simulations, the high burden that the investment cost imposes, prevents the integration of batteries. However, following the decreasing trend in the price of this technology in the past years, and the emergence of new laws that facilitate their incorporation, it is expected that batteries will start to integrate slowly in the electricity system of the buildings.

- A potential uptake of solar PV, induced by the rise in the number of prosumers, will induce a higher de-centralisation in the production of electricity, which will pose challenges to the energy system. Fluctuations in the grid will most likely occur, affecting considerably the price of electricity and the traditional business model of the energy stakeholders. Higher rates of distributed generation will induce the appearance of new policies and laws. New market opportunities for prosumers and utility companies will happen. Due to the impact of distributed generation, the business model of utilities will need adjusting. The changing role of the grid will facilitate the transition into the Smart Grid, facilitating the integration of other appliances in the system such as storage systems.

- Batteries can provide many flexibility options for the future energy grid. The inclusion of higher shares of intermittent power generation will introduce instability into the system, which could be counteracted with the use of storage systems. Residential buildings in particular can enjoy many non-financial benefits from batteries. Apart from increasing the self-sufficiency of the community, coupled systems can be useful from a resilient energy systems perspective. During periods of abnormal weather, batteries can sustain the system by shifting loads through Demand Side Management policies.

- The current energy grid is still adapted to the centralized structure. The future of the energy market in Sweden will be determined by the will of society to take active part into the energy transitions and the technological developments that are expected to happen in the forthcoming years. The natural development suggests that the system will evolve from a decentralized or distributed network to micro-grids or island solutions. This will need modelling & investment with easier regulation frameworks and technical appliances ready for them. The potential smart grid features could provide a platform for the creation or smart interconnected micro-grids or nested networks. This way production will achieve its higher flexibility highly relying in prosumers as key players in the market.

8

Future Work

This Master Thesis probes on the motives and barriers for non-individual adopters to enroll in prosumerism and the benefits it brings to the communities.

To improve the investigations and keep researching on the matter, further work can be done. Below, some possibilities are presented:

- The natural evolution of this Master Thesis would be to investigate the factors affecting the deployment of micro-grids and their current situation in Sweden. Besides, a viability study of these could be implemented, both at an autarkic and non-autarkic level. The conceptual model developed in this Thesis could be amplified by including the factors involving micro-grids and provide a broader overview of the factors affecting prosumerism.

- Studying the way prosumerism affects utilities can help to improve the knowledge on the consequences brought by this business model. Apart from that, the solutions that utilities will have to create to ensure the profitability of their business model could be studied.

- Probe on the impact that the inclusion of the Smart Grid will have for prosumers and the way this will improve their economic situation. Study the benefits of its inclusion for the electrical system of the buildings and quantify the reduction in consumption induced by it.

- Investigate the new business models that will arise for prosumers impulsed by the transformation of the current laws governing prosumerism.

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A

Appendixes

Appendix 1. Table with parameters, variable and their corresponding equations and units of the SFD

Variable Name	Equation	Units
Adoption rate	Effective adoption fraction*Nominal contact rate	Consumers/Year
Annual prosumer production	Average building solar PV capacity*Solar PV yearly yield	kWh/Year
Annual stored electricity	Annual average prosumer production*0.1	kWh/Year
Available effective information on solar	Information effectivity factor*Word of mouth factor	Dimensionless
Average building solar PV capacity	150	kWp
BSS adoption rate	Effective adoption fraction BSS*BSS nominal contact rate	Consumers/Year
BSS investment cost	$(10^4), (1, 950000), (3, 900000), (5, 880000)$ (7,870000),(13,850000),(15,840000)	SEK
BSS nominal contact rate	Potential BSS adopters concentration*Prosumers with BSS*Time converter	Consumers/Year
Correlation factor of likelihood to adopt with the economic reality	10^{-6}	1/SEK
Cost of Capital	0.019	Dimensionless
Economic reality of BSS	Savings per year from BSS/Time converter-BSS investment cost*0.033	SEK

Economic reality of solar PV	(Savings per year/Time converter)-(LCOE*Annual average prosumer production)	SEK
Effective adoption fraction	Potential prosumers concentration*0.5*(Available effective information on solar+Likelihood to become a prosumer+Nominal adoption fraction)	Dimensionless
Effective adoption fraction BSS	Likelihood of adopting BSS+Potential BSS adopters concentration*0.1+Nominal adoption fraction BSS	Dimensionless
Electricity price	Variant	SEK/kWh
Factor to normalize motives to adopt	0.05	Dimensionless
Grid Consumption	Net energy annual consumption-Total solar energy production	kWh/Year
Grid parity	LCOE/Electricity price	Dimensionless
Information effectivity factor	0.5	Dimensionless
Initial investment cost per capacity	Variant	SEK/kWp
LCOE	Subsidized cost*((1 + Cost of Capital)^{30})/(Annual average prosumer produciton*systems lifetime)	SEK/kWh
Likelihood of adopting BSS	(-Economic reality of BSS*Correlation factor of likelihood to adopt with the economic reality)/(Grid parity)	Dimensionless
Likelihood to become a prosumer	(Economic reality of solar PV*Correlation factor of likelihood to adopt with the economic reality)+(Word of mouth factor *Normalization factor for word of mouth)+(Motives to adopt solar PV)	Dimensionless
Motives to adopt solar PV	Factor to normalize motives to adopt*Motives to adopt switch	Dimensionless
Motives to adopt switch	1	Dimensionless
Net energy annual consumption	$8.29 * 10^6$	kWh/Year*Cons
Nominal adoption fraction	0.075	Dimensionless

Nominal adoption fraction BSS	0.05	Dimensionless
Nominal contact rate	Potential prosumers concentration*Prosumers*Time converter	Consumers/Year
Normalization factor for word of mouth	0.25	Dimensionless
Potential adopters of BSS	INTEG (Total prosumers-BSS adoption rate,Total prosumers)	Consumers
Potential adopters of PV	INTEG (-Adoption Rate,10000)	Consumers
Potential BSS adopters concentration	Potential adopters of BSS/(Potential adopters of BSS+Prosumers with BSS)	Dimensionless
Potential prosumers concentration	Potential adopters of PV/(Prosumers+Potential adopters of PV)	Dimensionless
Prosumers	INTEG (Adoption Rate,1288)	Consumers
Prosumers with BSS	INTEG (BSS adoption rate,50)	Consumers
Savings per unit	(Electricity price-LCOE)	SEK/kWh
Savings per year	Annual average prosumer production*Savings per unit	SEK/Year
Savings per year from BSS	Annual stored electricity*(Electricity price-0.66*Electricity price)	SEK/Year
Solar PV yearly yield	950	kWh/Year*kWp
Subsidies	Variant	Dimensionless
Subsidized cost	(Average building solar PV capacity*Initial investment cost per capacity)*(1-Subsidies)	SEK
Systems lifetime	30	Year
Time converter	1	1/Year
Total prosumers	Prosumers	Consumers
Total solar energy production	Annual average prosumer production*Prosumers*Unit converter	kWh/Year
Unit converter	1	1/Consumers
Word of mouth factor	Prosumers/(Prosumers+Potential adopters of PV)	Dimensionless

Appendix 2. Questions from interviews

1. How would you describe the organization on whose behalf you are answering these questions?
2. How would you describe your role in the organization you are representing?
3. How long have you been working in this organization in your current capacity?
4. Can you discuss a bit about the solar PV and battery storage system in your building?
5. Can you expand on the motivations for installing the system?
6. Can you discuss the different people or groups of people you had to work with, to get the system up and running?
7. Can you tell us the different challenges you faced, regarding this system?
8. Can you tell how the economic benefits of the system are distributed among the different stakeholders involved in the running of the system?
9. What are the benefits you organization gains from it?
10. Do you think you will like to go ahead with this model of prosumerism in other buildings?
11. Is it possible for you to elaborate and discuss your experience with solar PV systems or/and batteries, either professionally or personally?
12. What are your opinions/thoughts on the suitability of de-centralized household level solar PV in Sweden?
13. What do you think are the benefits of de-centralized household level solar PV in Sweden?
    - Benefits for the owner of the solar PV system
    - Benefits for the wider society
    - Benefits for the local grid company
14. What do you think are the drawbacks of de-centralized household level solar PV in Sweden?
    - Drawbacks for the owner of the solar PV system
    - Drawbacks for the wider society

- Drawbacks for the local grid company

15. What do you think are the prospects of de-centralized household level solar PV coupled with battery storage systems?

16. Do you think solar PV coupled with battery storage systems are better or worse for future electricity systems?

    - What are your reasons for the answer above?

17. What would you say is the biggest challenge to the inclusion of micro-generation being fed into the local grid?

18. Do you think the grid-operators are incentivized by the governmental policies and Svenska Kraftnät to prioritize the inclusion and feeding-in of the micro-generation into the local grid?

    - or example, I have heard it being said that the local grid operators are forced to make investments into changing transformer sub-stations but the funding to upgrade it to make the technical option of feeding-in micro-generation smooth, is difficult because of the cost. Do you think this is true?

19. Do you think micro-generation is environmentally beneficial, for the cost or challenges a local grid operator and a prosumer has to face, in Sweden?

20. What are your thoughts on micro-grid (that might go off-grid)?

    - Have there been any signs of development of a micro-grid among your customers or has “the company/municipality” hade thoughts about implementing a micro-grid?
    - What would this imply for you? Would a micro-grid result in any benefits and/or challenges?
    - Who would you need to cooperate with?

21. Is a prosumer having a battery storage system better for the grid operator than just having solar PV panels, without storage options?

    - If yes, why so
    - If no, why so

22. Do you think the electricity pricing policy of Sweden is ready for serious prosumers?

23. In literature, increase of prosumers with storage systems are an economic

challenge to the grid operators because the electricity price will increase when the consumption goes down. Do you think this problem will arise for local grid companies in Sweden, as well?

- If yes, when do you think this problem will arise?
- How can or will they be ready for such a situation?

24. What do you think the grid operation and electricity distribution business will look like in the future?
25. Do you have any other thoughts to add, besides what you have already spoken about?