CHALMERS
UNIVERSITY OF TECHNOLOGY

Solar photovoltaics in Västra Götaland

Analysing the technological innovation system dynamics

Master's thesis in Innovative & Sustainable Chemical Engineering and Industrial Ecology

USISIPHO GOGELA
VASILIS DROGKOULAS

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

Solar photovoltaics in Västra Götaland

Analysing the technological innovation system dynamics

USISIPHO GOGELA
VASILIS DROGKOULAS

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

Solar photovoltaics in Västra Götaland
Analysing the technological innovation system dynamics

USISIPHO GOGELA
VASILIS DROGKOULAS

Supervisors: Johan Larsson and Kristina Hojcková
Examiner: John Holmberg

Department of Space, Earth and Environment
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden

Cover: A solar photovoltaic system in Mölndal
Photographer: Usisipho Gogela

Gothenburg, Sweden, 2019

Solar photovoltaics in Västra Götaland
Analysing the technological innovation system dynamics
USISIPHO GOGELA & VASILIS DROGKOULAS
Department of Space, Earth and Environment
Chalmers University of Technology

Abstract

The reduction of emissions from energy generation is one of the key interventions that can be made to meet climate goals. In order to achieve this, a shift to renewable energy will be required. In West Sweden, despite the energy sector's importance in reducing carbon emissions, the regional climate policy (Klimat 2030) is not at the forefront of the goals. Sweden's electricity mix is already almost entirely carbon-neutral. The grid is currently dominated by nuclear and hydropower, with wind making gains in many regions. However, solar power makes up less than 1% of the electricity mix. Actors from the regional energy agency have described the solar power sector in the region as scattered, comprising of many small actors who do not collaborate or coordinate, and thus difficult to influence.

The purpose of this thesis is to identify and map the key actors in the solar photovoltaics sector in Västra Götaland and investigate the drivers and barriers affecting solar PV diffusion in Västra Götaland.

Thus, the regional energy office cites the low uptake of solar as an area of interest, which led to the research question of "What are the technological innovation system dynamics in the Västra Götaland solar photovoltaics sector?"

A backcasting approach was used as a foundation for the work. A system mapping was performed, quantifying the total installed capacity, yearly capacity installation of solar in the region, and identifying key actors, networks and institutions. A technological innovation system framework was used to describe and analyse the uptake of solar photovoltaics in the region. The framework was applied to contextualise the rate and nature of uptake, with relation to innovation drivers, barriers, speed of diffusion and actors, networks, and institutions. A semi-structured interview process was undertaken, gathering data from 13 stakeholders working in the solar energy sector. The interview data gathered were used along with literature to reach the results.

The prominent drivers supporting the uptake of solar found to be strong knowledge diffusion to customers, high legitimacy, government subsidies supporting solar PV market formation, although it was acknowledged that they should be addressed on a national level, and niche applications. Conversely, the main factors hindering the transition were determined to be a lack of knowledge development, lack of human capital and long-term policy uncertainty.

Keywords: *solar photovoltaics, backcasting, technological innovation systems, sustainability transitions, multi-stakeholder processes*

Acknowledgements

We would like to express our appreciation to our two supervisors Kristina Hojcková and Johan Larsson for the invaluable support they provided, with their experience, their critiques and guidance, and mostly for the invaluable encouragement through the various steps of the research. We are particularly grateful for the support and the advice given by John Holmberg as it was crucial to determine and validate our direction of focus. Special thanks should be given to Linnea Johansson as well as Andreas Hanning and Gavin McCrory for the assistance, advice and all the discussions in the lab.

We would also like to extend our thanks to all our fellow Challenge Lab students: Abdal, Annica, Ashwin, Hani, Hanna, Nora, Per, Sou, Spiros and Viktor for a great experience, interesting discussions and the valuable help. Also, to all the lecturers from Chalmers for the inspiration and knowledge that they provided. Special thanks to the Swedish Institute for providing scholarship funding for one of the authors.

Last but not least, to the family, friends and loved ones that supported, encouraged and tolerated us during this period.

Usisipho and Vasilis,
Gothenburg, June 2019

Table of Contents

List of Figures and Tables

1 Introduction

Region Västra Götaland has been one of the most determined in the effort against climate change, with stricter goals than the EU, grouped in a vast goal called Klimat 2030. The main categories of focus are: smart buildings, food and health, mobility and renewable/resource efficient goods and services. Besides the category of smart buildings, the Challenge Lab master's thesis arena (which will be introduced in Chapter 1.4) addresses the rest. However, it has been identified that one key source of emissions is absent from the targets; energy. It is missing mainly because it is involved in all 4 categories in larger or smaller extent. However, that makes it less concrete and thus deters from organised planning for energy transition in the region on a large scale.

Renewable energy is increasingly promoted to combat CO_2 emissions, with it being about two thirds of the annually added capacity, according to the International Energy Agency (IEA, 2018). Specifically, solar energy has seen a rapid decrease in cost to a point where it may cost half as much as electricity from coal (Lazard, 2018). However, these studies do not include the storage cost of solar energy, which is one of the proposed solutions for the variability of renewable electricity generation. Some small-scale projects are taking place in the Västra Götaland region (for example initiatives like Sol i Väst), however the actors and the projects are all small and thus difficult to find a big initiator of change, according to actors from the regional energy office. The regional energy office actors add that communication and collaboration within the sector are also serious issues due to the fragmentation.

1.1 Thesis Outline

Chapter 1 provides an introduction to the work, motivations for the work, and the aim and research questions. Furthermore, the section provides details about the Challenge Lab, a master's thesis arena aimed at addressing sustainability transition challenges.

Chapter 2 provides the topic background. This is done with regard to the current state of solar PV in Sweden more broadly, and Västra Götaland in particular.

Chapter 3 describes the theoretical framework, introducing the Backcasting method and he Technological Innovation Systems (TIS) approach.

Chapter 4 describes the methods employed, from system mapping, to the data collection and analysis process.

Chapter 5 of the work presents the results, with a structure following that of the TIS functional analysis approach.

Chapter 6 is a discussion, relating the results to the background, aim and research questions. Reflections are made concerning the method and limitations of the study.

Chapter 7 concludes the work by pointing out the most notable findings. These include drivers, barriers, and recommendations.

The Appendix contains the interview template, as well as further details of the work leading up to the formulation of the research question.

1.2 Aim

Despite there being literature on the solar PV sector in Sweden, there is a lack of work focusing on the Västra Götaland region in particular; which will be the contribution of this work. The aim of this thesis is to analyse the technological innovation system dynamics of solar PV in Västra Götaland. This will consist of the following: (i) identify and map the key actors in the solar photovoltaics sector in Västra Götaland, (ii) investigate the drivers and barriers affecting solar PV diffusion in Västra Götaland.

1.3 Scope

The technological innovation system of focus is solar photovoltaics for the production of electricity. Some reference is made to solar thermal, as the diffusion of these systems has historically occurred in parallel and has had a connection/interplay in the region. The spatial region of focus is Region Västra Götaland, a county located in the west of Sweden. However, reference is made to the rest of Sweden, as well as the international context, such as Germany and China. In terms of time, a snapshot of the current state of the PV sector is provided. Some reference is made to the recent progression of the solar PV sector in order to improve analytical clarity, where necessary.

1.4 Research Questions

In relation to the aim of the work, we pose the main research question:

"What are the technological innovation system dynamics in the Västra Götaland solar photovoltaics sector?"

The objective behind the question is to describe why the uptake of solar PV has been limited in Västra Götaland. By studying the technological innovation system dynamics, it is expected to gain an understanding of the structure and innovation processes of the solar PV sector in Västra Götaland. Hence, this will allow identification of specific points of intervention.

The research question thus consists of the following subquestions:

1. Which are the main actors, relations and regulations regarding solar photovoltaics in Västra Götaland, and what are their roles?
2. What are the main drivers and barriers affecting the diffusion of solar PV in Västra Götaland?

1.5 Method for formulating Research Questions

The research questions above were formulated following a process at the Challenge Lab, a master's thesis arena aimed at addressing sustainability transition challenges. This subsection describes the process of formulating the research question.

1.5.1 Introduction to Challenge Lab

Challenge Lab serves, since its creation in 2014, as an arena that creates space for students from different educational or cultural backgrounds and stakeholders from industry, academia, and the public sector to work together. The arena enables these actors to collaborate and contribute towards sustainability transitions. Additionally, the lab facilitates the creation of links between different actors. The main idea is to act as a catalyst between the triple helix, as illustrated in Figure 1, in a neutral and inviting manner (Holmberg, 2014).

The Challenge Lab process is divided into two stages - Phase 1 and Phase 2. Phase 1 consists of the of the formulation of a research question, with relation to sustainability principles, personal values, together with dialogues with societal stakeholders. Phase 2 consists of addressing the defined research question. The overarching framework that has been used in the Challenge Lab pedagogical activities and through the research question exploration and planning is backcasting. This methodology begins with the setting of the criteria for a sustainable future, based on basic, sufficient, and non-overlapping sustainability principles (Holmberg & Larsson, 2018).

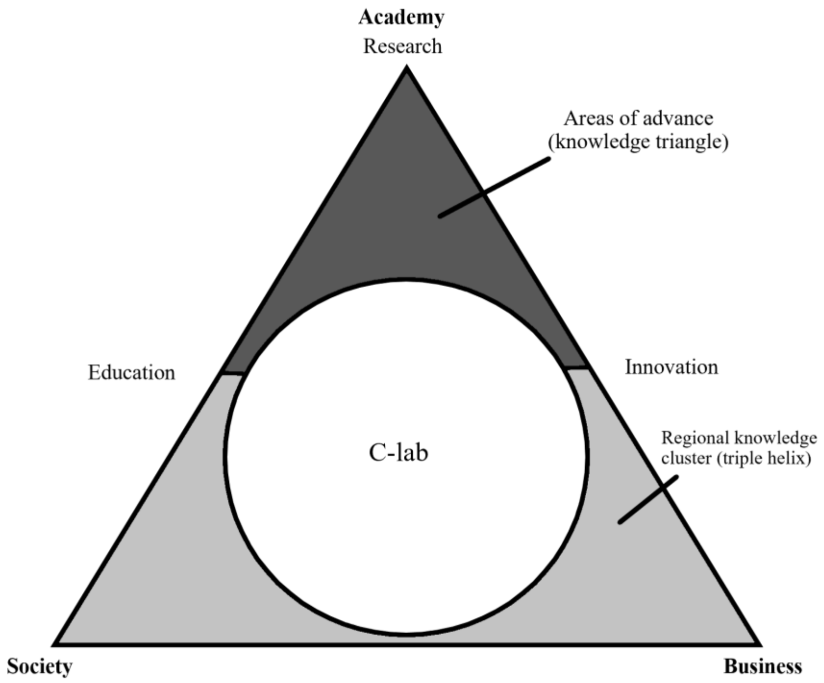

Figure 1: The triple helix of academia, business and society, adopted from Holmberg (2014)

The core of its process involves the analysis of certain challenges in a regional level. This includes the identification of "energy" and interest towards certain aspects and issues, analysis of transition, innovation and collaboration processes from a literature point of view. Furthermore, a combination of these, with the goal of identifying the gaps between the current situation and the desired future. Leverage points are identified and worked with to bridge those gaps. Although there is focus on the process itself, the students and the Challenge Lab staff try to produce as meaningful contribution as an outcome.

Besides the fulfilling aspect of the Lab the bonding between the participants is valuable by itself. Through this process, and especially Phase 1 of the project, students become familiar and develop their collaborating, facilitating and leadership skills. There is also the access to an amount of diverse information about the current status in the region that is hard to obtain otherwise, which can be of a big assistance to the students in their future.

2 Background: Solar PV in Sweden and Västra Götaland

This chapter provides an overview of the current state of the solar photovoltaics sector. It begins with a general description of the Swedish PV sector. This is done in terms of uptake statistics, national targets and policy, actors, drivers, and barriers. The section then narrows down to focus on Region Västra Götaland.

2.1 Solar PV in Sweden

Up until the start of the 2000s, the solar PV market in Sweden was made up of mostly small, off-grid systems. These were mainly used for holiday homes, mobile homes / caravans, and maritime applications. However, since the mid 2000s, grid-connected systems have grown considerably - with about 15 times as much grid-connected capacity as off-grid capacity at the end of 2016. Of this capacity, approximately 32% consisted of systems on private homes and 62% on public, commercial, or agricultural buildings. Solar parks made up the minority, accounting for only 6% of capacity. This large portion of small and medium-scale installations may be the reason for the perceived “fragmentation” in the sector.

As of 2016, the estimated installed capacity in Sweden was estimated at 141 MWp (Lindahl, 2016) and 192.9 MWp (IEA, find in Lindahl report). In 2018 this figure had increased to 411 MW of solar PV nationally. Systems with less than 20 kW capacity account for 46% of generation capacity, and 84% of the number of installations (Bellini, 2019).

In 2016, the Swedish government agreed on a long-term energy policy. The policy targets are the following (Swedish Government, 2016):

- 50% more efficient use of energy (measured by energy use relative to GDP) by 2030
- 100% renewable electricity production before 2040
- Zero net greenhouse gas emissions by 2045, followed by negative emissions in following years.

To support these ambitions, since 2012 the government (in cooperation with Norway) has had a supporting scheme for renewable electricity generation. This is known as the renewable (or green) electricity certificate system. The support scheme is expected to last until 2030, with a target of 18 TWh of renewable electricity generation. However, this scheme is technology-neutral, and applies to all forms of renewable energy, not just solar PV (Swedish Energy Agency & NVE, 2017). To support solar specifically, a capital investment subsidy has been in place since 2009, aiming to facilitate an increase in PV installation. Initially, the subsidy covered 60% of the capital costs of a PV system (Lindahl, 2016), but has been subsequently lowered in following years, and now stands at 20% (Swedish Energy Agency, 2019).

2.2 Actors in the Swedish solar PV sector

Earlier literature identifies three main types of actors on the supply-side of the Swedish PV value chain: i) cell manufacturers, ii) modular manufacturers and iii) system installers and buyers (Porsö, 2008). However, these first two groups have diminished in importance over the years. Local manufacturing of cells and modules is limited, with the vast majority of cells and modules now being imported from Asia (Lindahl, 2017). In more recent literature, Marklund and Ramberg (2018) employed stakeholder theory and analysis to characterise actors found in the Swedish electricity context, with focus on the solar PV sector. A power/interest matrix was used to classify stakeholders. According to Marklund & Ramberg, the most prominent stakeholders (on a national Swedish scale) were found to be (Marklund & Ramberg, 2018):

- Regulators
- Private customers
- Property companies
- Business / corporate customers
- Public sector customers
- Distribution network/system operators
- Power suppliers

They further add: *"New actors are on the rise, and integration between different industry sectors (when digitalization and technology become incorporated in various products and services) is likely to enable collaborations beyond solely the stakeholders of the energy market."*

Aguilar (2013) echoes these newer findings on actors, stating that some of the most prominent stakeholders include large property owners, as well as homeowners. Additionally, Palm (2016) cites utility companies and local organisations promoting solar PV as important actors, such as local bottom-up citizen initiatives advocating for solar. The presence of utility companies providing solar PV options is thought to be more encouraging to customers than installation-focused companies. This is due to a higher (perceived) credibility and decreased customer risk.

Palm (2016) further states that current research suggests that local factors are an important consideration in the diffusion of solar PV (Palm, 2016). This holds even down to very small spatial scales, with research finding that peer effects are valid even down to the street and local postal code level.

2.3 Drivers supporting diffusion

Previous literature has found a number of drivers for the Swedish solar PV sector. These include the following:

Financial / economic factors

Financial / economic considerations are generally considered a driver, with solar PV system prices dropping considerably in recent years. Additionally, solar PV investment support from the Swedish state has further improved the financial viability of solar installations (Aguilar, 2013, Marklund & Ramberg, 2018). Furthermore, excess electricity produced can generally quite easily be sold to the grid at a price equal to or higher than the spot price (Palm, 2016), largely due to the aforementioned renewable energy certificates.

A way of demonstrating being environmentally friendly

Previous research has found that solar PV is generally perceived as legitimate in Sweden. This is a driver, as companies can use it as a form of marketing, promoting themselves as being “green” (Aguilar, 2013). Marklund & Ramberg (2018), express a similar idea and state that solar is often installed for “environmental” reasons. The authors add that installing solar PV can be seen as a way to project the image of sustainability externally, often for marketing purposes. Palm (2015), cites the high legitimacy of solar PV, as well as institutional changes (such as supporting policy) as notable drivers. In further work, Palm (2016, pg. 2) elaborates on this finding, and mentions solar’s positive public image. The author states that solar is seen as *“a way to demonstrate an ecological lifestyle to neighbors and friends”*. Lastly, surveys and polls of the general public confirm these sentiments. A poll conducted by E.ON found that 73% of Swedish citizens interviewed wanted to install solar panels (E.ON, 2016). According to public surveys, 80% of Swedish homeowners believe that efforts to increase solar PV should be increased (Hedberg and Holmberg, 2017).

Information sharing

Peer effects and citizen initiatives promoting solar through word of mouth, person-to-person interactions are seen as a driver, quite closely linked to legitimacy (Palm, 2016).

Self-sufficiency

Self-sufficiency as a driver has also been noted. For consumers, producing one’s own electricity is often seen as a way decrease dependence on the grid and market prices (Aguilar, 2013). There is some disagreement on its importance as a driver, as some authors believe it to play only a small role, though expect its importance to grow over time (Marklund & Ramberg 2018).

Collaboration between industries

Other drivers encouraging the uptake of solar were found to in the potential collaboration between different industry sectors, for example solar PV and information technology (Marklund and Ramberg, 2018).

2.4 Barriers hindering diffusion

Marklund & Ramberg (2018) describe barriers as:

- uncertainties concerning: long-term regulations, the status of incentives and financial competitiveness of solar, and solutions for the storage of energy produced by solar.
- complicated bureaucracy, though the authors do not clearly define this term.
- difficulty with modifying existing grid infrastructure to support solar, such as storage systems and improved interconnectedness between regions.
- intermittent nature of solar energy production

The authors further add: *"increased investment support for customers may be the wrong way to achieve more solar in the grid if it coincides with for example DSOs or electricity suppliers unintentionally holding back infrastructural investments due to regulations, or if the process of joining the system is overly complicated."* - *Marklund & Ramberg (2018)*

Palm (2015), adds further to the issues related to incentives to install solar PV, stating that the Swedish subsidy system has a cap on the total value of financial support provided. This has effectively set a cap (limit) to the demand. The author suggests that remedies to this may include removing the cap, or reducing the percentage of costs covered per system for the subsidy. Lessons from the German context could be adapted, where PV subsidies were regularly adjusted in response to price fluctuations or technical changes.

Furthermore, Palm (2015) cites uncertainties in the subsidies as a barrier, as per Marklund & Ramberg (2018). The evolution of the amount of payment support received for PV systems is uncertain. This discourages investment as it makes financial viability of projects less certain. The author recommends that this could be remedied with the implementation of a *"transparent and planned"* reduction in subsidies.

2.5 Solar PV in Västra Götaland

The solar PV sector makes up a small share of the total grid mix. As of 2018, solar PV made up approximately 0.4% of Sweden's annual electricity production. For Region Västra Götaland specifically, as of 2016, solar PV accounted for 18.3 MW of the 140 MW total solar PV production in Sweden. In 2018, this figure increased to 62.5 MW out of a total 411 MW of solar PV nationally (Swedish Energy Agency, 2019) .

Table 1: Number of solar PV installations and installed capacity in Västra Götaland

Year	Number of solar PV installations	Installed capacity (MW)
2016	1645	18.34
2017	2416	29.73
2018	4190	62.49

The regional government's current role appears to be one of supporting information sharing and network formation by supporting the energy office. Additionally, the regional government has supported the sector by using public procurement policies as a way to stimulate market formation. That is, installing solar PV on government buildings to help create some of the demand necessary for the growth of the industry.

According to stakeholders from the regional energy office, the Västra Götaland solar PV sector can be described as "scattered" and "fragmented", with a large number of actors. Additionally, these stakeholders add that there is generally little collaboration between companies in the sector. The most active portion of the value chain is thought to be downstream - with the bulk of market activity occurring with consultants and installation companies. Local production and assembly of solar cells and peripheral equipment is thought to be limited.

However, in terms of research and development, niche and integrated applications are thought to be receiving some attention among actors in the region - largely from universities, research institutions and small businesses. At Chalmers University of Technology, there are an estimated 39 full-time jobs focused on solar energy (and related) research. These range from roof applications, organic solar cells, battery research, and solar energy applications among others (Lindahl, 2017).

In terms of the largest market segment, there is uncertainty and disagreement among industry actors. Some believe the dominant market segment is small-scale residential installations on the roofs of private homes. Other actors cite installations on commercial and industrial buildings as the biggest market share. However, there is widespread agreement that together, the aforementioned segments dominate, with utility-scale solar parks making up a small portion of the total market share.

With that said, Västra Götaland currently has the largest solar park in Sweden, Nya Solevi. The park is located in Säve, Gothenburg, and produces 5.5 MWp. The park originated from local citizen demand, with the project being spearheaded by a local energy utility, Göteborg Energi.

3 Theoretical Framework

Literature was used as a basis for formulating the interview guide, and as well as a framework for analysis of the data obtained. The main theory used was backcasting and the technological innovation systems (TIS) approach.

3.1 Backcasting

In the introduction, the effort to tackle global sustainability challenges was highlighted. However, the goals are still not being met and the rate towards meeting them is not fast enough, as it has been stated by the United Nations (Reuters, 2017). In fact, as Holmberg (2014) mentions there is a limited system perspective in the decision making; it is rather focused on the last parts of the cause-effect chain. This is critical since today's ecological challenges have a global, complex and interconnected character, which means that a change of approach and tools is necessary. In that sense backcasting gives a different and unconventional perspective to problem solving. As mentioned by Vergragt and Quist (2011), it includes envisioning the desired future that complies to certain criteria and then getting back to the present situation, from where policy makers or strategists plan a way that can lead to that future. That means the planning goes some steps back towards the roots of the problem, thus creating more effective (and structure-changing) solutions.

Bearing in mind this property of backcasting and also the general need for an approach shift, it is beneficial to know the specific circumstances and problems that call for that shift. The five main occasions that have been identified by Dreborg (1996) to use backcasting are:

- *"When the studied problem is complex*
- *When there is a need for major change*
- *When dominant trends are part of the problem*
- *When the problem is a matter of externalities to a great extent*
- *When the time horizon is long enough to allow considerable scope for deliberate choice*"

The main benefits of using backcasting, are the fact that it provides reliable and systematic approach to the planning procedure. Also, it can lead to preparedness for future market changes and avoid costly and damaging events before they even take place, for example the handling of toxic waste (Robert and Holmberg, 2000).

Backcasting as a problem solving process is split into 4 main steps, which are mentioned below and then illustrated in Figure 2.

1. *Frame conditions for a sustainable future on a level of principles*
2. *Analyse gaps between the present situation and the sustainable future*
3. *Identify leverage point interventions for bridging the gaps*
4. *Create strategies for realising the leverage point interventions*

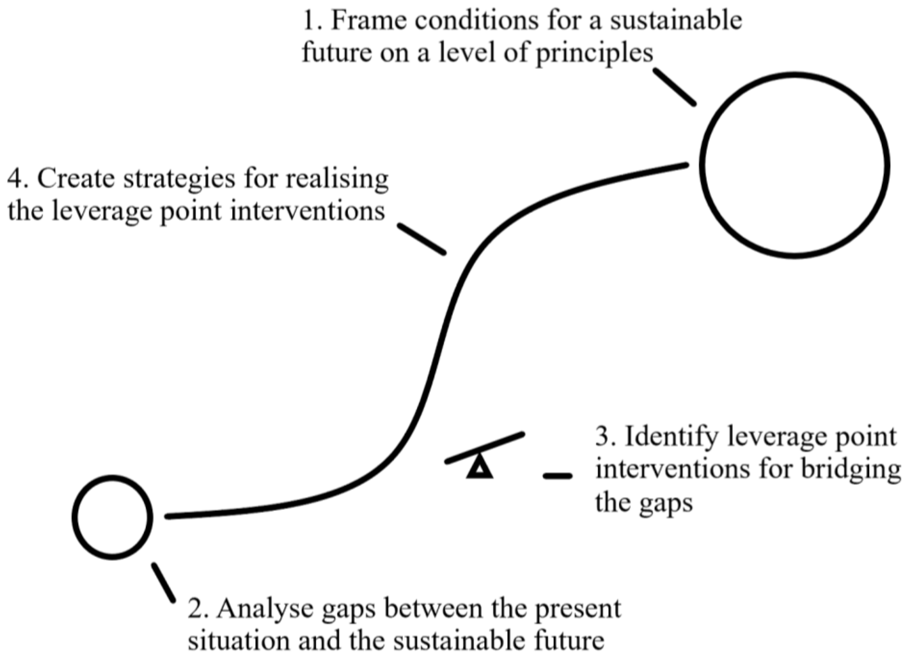

Figure 2: Schematic of the backcasting methodology from sustainability principles as adapted from (Holmberg and Larsson, 2018)

These steps were further analysed using two different perspectives, an outside-in perspective that includes the knowledge, tools and methods to face the new requirements of systems caused by global sustainability and an inside-out perspective that includes again knowledge, tools and methods that fit with the students' own values and strengths with the goal of handling the relations and interactions between the stakeholders in the system (Holmberg, 2014).

Step 1 - Criteria for a sustainable future

To begin with, backcasting starts with the definition of criteria for a sustainable future, based on principles. In this way, the process begins in a future state resembling a start from scratch, without the added burden of extrapolated current processes that could be part of the problem (Holmberg, 1998). These criteria are categorised in four pillars with each one of them referring to a different aspect of sustainability. The natural environment consists the base upon which the various human activities can be built as it can be seen in Figure 3 below

Figure 3: Schematic of the backcasting methodology from sustainability principles as adapted from (Holmberg and Larsson, 2018)

Criteria for a sustainable future: outside-in approach

Looking at the literature that holistically considers the factors affecting the four dimensions, the authors get more perspectives and views of the desired future. Holmberg (1998) states that: "In order for a society to be sustainable, nature's functions and diversity must not be systematically:

1. Subject to increasing concentrations of substances extracted from the earth's crust
2. Subject to increasing concentrations of substances produced by society
3. Impoverished by over-harvesting or other forms of ecosystem manipulation

4. Resources must be used fairly and efficiently in order to meet basic human needs worldwide."

Those are further analysed by the nine "planetary boundaries" which set the limits for a healthy human activity within earth's limitations system. These planetary boundaries set the categories of focus but also the quantitative limits of absorption of human impacts. The systems are interconnected, where the transgressing that occurs in one, affects the other systems (Rockström et al., 2009). Deviations from the natural state of the boundaries that are large in comparison to the natural variation capacities should be prevented, or at least they should not continue to increase systematically. (Holmberg and Larsson, 2018).

The inclusion of the human factor is important to complete the backcasting process. The UN Sustainable Development Goals are a characteristic example of envisioning a sustainable future, again from an outside-in approach, with a combination of natural, societal and economic aspects. That results in 17 broad goals that are intended to be accomplished within 15 years since their adoption in 2015 (UN, 2015). Adding to that the wellbeing aspect of sustainability is also pointed by the very definition of sustainability by Brundtland (Brundtland et al, 1987).

Criteria for a sustainable future: inside-out approach

Personal views, values and needs should be considered to complement the outside-in approach in order to keep the dimensions relatable aside from helpful.

Three psychological needs are prerequisites for a person to express and be self-motivated; competence, autonomy and relatedness (Ryan and Deci, 2000). Autonomy means that the behaviour and actions of the individual are independent from other actors or actions (for example punishment or reward). Competence is the degree of fulfillment of the individual's actions that allow the creation of intrinsic motivation. They gain joy just by the completion of this action and they do not need external driving forces to push them. Relatedness is when this action is relevant and thus has received recognition as an outcome.

Step 2 - Gaps between present and future

The second step of backcasting is the process of understanding the current state of the system and as a result, finding the gaps and challenges in order to reach the desired future. The desired level of understanding is when it is clear which are the challenges that need to be faced if transition is desired.

Gaps between present and future: outside-in approach

To get the holistic overview of the system at its current state, the multi-level perspective (MLP) from Geels (2002) is used. It gives a multidimensional view of the societal structures and technology, which can be useful to interpret socio-technical changes and support transition processes. There is linkage between the three levels, since by elevating from the bottom one (niches) to the top (landscape) there is an increased structuration of activities in local practices or as a result less flexibility (Geels, 2002). The three levels of MLP, presented in Figure 4 are the landscape in the macro-level, the regime in the meso-level and the niches in the micro-level.

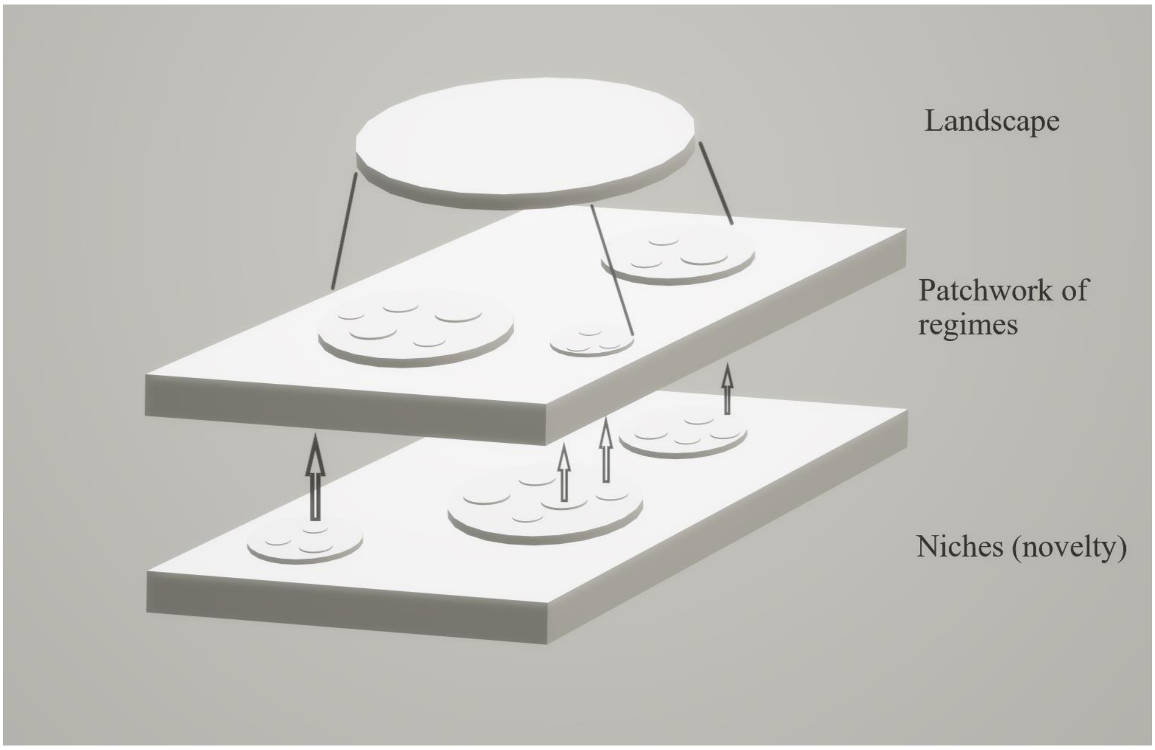

Figure 4: Schematic of the backcasting methodology from sustainability principles as adapted from (Holmberg and Larsson, 2018)

Regarding the components of each level, landscape reflects the existing material or social infrastructure. It has a wider application range in space and frequency and is more difficult to be influenced (Geels, 2005). As a result, it becomes the most distant out of the three, regarding the connection with the other levels. Regime, on the other hand, encompases technological regimes in their broader definition of engineering and manufacturing practices, skills, procedures and product characteristics, and also social groups and firms (Geels, 2005). Some sub-grouping is present to an extent, giving each group a certain amount of autonomy. At the same time relations outside of them are still present. These relations are also changing depending on the researcher's approach. For example, they will be different on an institutional level, compared to the relations on a cultural level. Finally, niches are the micro-level of the MLP and they encompass usually small-scale efforts to change things in the regime or simply join it. Most of the time they are connected to already existing subgroups from the regime level, since it makes it easier to lift to the meso level. Joining the regime in a distinct area is a big challenge niches and thus innovation in general face.

Gaps between present and future: inside-out approach

The inside-out approach in this step will be firstly about understanding the positive and negative interactions between humans in the form of cycles (Sandow and Allen, 2005), then to enhance the positive interactions, a dialogue-based approach of leadership is used. The dialogues will create trust and therefore collaboration between the participants. Knowledge can be shared among the participants because of the lack of usual obstacles like confidentiality issues. This enables double-loop learning which makes learning faster and people more open to change (Argyris, 1977).

Step 3 - Envisage a future situation that can bridge the gap

The six most effective of the twelve possible places of intervention according to (Meadows, 1999), that were highlighted by her, starting from the most effective to the least, are:

- "The power to transcend paradigms
- The mindset of paradigm out of which the system-its goals, structure, rules, delays and parameters-arises
- The goals of the system
- The power to add, change, evolve, or self-organise system structure
- The rules of the system (incentives, punishments or constraints)

- The structure of information flows (who has and who doesn’t have access to what kinds of information)”

Step 4 - Find strategies for sustainable solutions

This step was not reached during the first phase but it is a possibility for the second one. Our group’s topic involves around the second and third step of backcasting so there is no purpose in further analysing this step.

3.2 The Technological Innovation Systems Approach

The Technological Innovation Systems (TIS) is a conceptual framework that can be used to analyse and describe the diffusion and maturity of systems (such as a technological sector), and hence identify policy issues and goals. A TIS is defined as *“a socio-technical system focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both)”*.

It consists of a group of social and technical components that work toward achieving a common goal or fulfilling an overall function (Bergek et al, 2008, p. 408).

TIS can be used an alternative to other theories, such as the market failure approach, which have generally been described as flawed or insufficient to describe innovation systems. This is largely due to their focus on economic market aspects, neglecting other system dynamics. This type of approach assumes that market forces will manage to direct systems towards development or growth. However, markets do not respond to surrounding factors, such as societal actors. Furthermore, the market failure theory suggest that intervention should be minimised, which removes the ability for experimentation and the learning process (Mazzucato, 2015).

Additionally, market failure approach refers to “perceived weaknesses” in the structure of a system, which are then said to result in “system failure”. A notable shortcoming of this approach is its lack of ability to describe how “good” or “bad” a part of the system is, without simply referring to its overall effect on the system described. TIS addresses these issues by complementing a structural approach *(structural components)* with a an approach considering the process too *(functional dynamics)* (Bergek et al 2008).

The analysis of consists of 6 steps, though these steps generally do not occur linearly. Analysis often requires the use of an iterative approach between the steps. These steps can described as follows (all steps adapted from Bergek et al 2008):

3.2.1 Defining the TIS in focus

This step deals with defining the focus of analysis. The three main kinds of choices to be made include: i) knowledge field or product, ii) breadth or depth of analysis, iii) spatial consideration, such as region/location. The choice of focus depends largely on the interests of the researcher, as well as the goals of the work. For example, a policy-maker would likely focus on an issue they work with directly and can influence in some manner.

3.2.2 Structural components

This step involves the identification of relevant *actors* in the system, such as companies along the value chain, universities, public sector organisations and so forth. Additionally, the identification of *networks* is required. These networks may include industry associations, partnerships, academic-industry links, customer-sales relations and so on. Both formal and informal networks can be considered, with the identification of informal networks often requiring conversations with involved industry actors.

Lastly, *institutions* form a part of the structural components. In this framework, institutions are defined as *"cultures, norms, laws, regulations and routines".* Even the lack of institutions may be the main point of interest, as this can lead to poor standardization and a fragmentation of the industry.

3.2.3 Functions and achieved functional pattern

Describing the *"functional pattern"* is the first step in this stage. It consists of describing how well the functions of the TIS are currently being achieved. However, there are no "normative" criteria in assessing the functionality of a TIS, as the functional pattern differs between systems, and over time.

The functional pattern can be described according to a number of functions. A function is a *"process that contributes to the development, dissemination or application of an innovation"*. TIS analyses systems according to 7 functions, which are summarised in the following table and then are described further:

Knowledge development and diffusion

This function deals with the knowledge-base of the TIS. Different types of knowledge can be incorporated in the analysis, including *"scientific, technological, production, market, logistics and design"*. Quantification of knowledge can be done using a number of methods, including bibliometrics (citations and publications), R&D projects, patents, learning curves, and expert opinion, for example.

Influence on the direction of search

For the maturation of a TIS, organisations should enter the sector. Furthermore, the incentives for the organisations to enter should be present. This function describes the manner in which these organisations deal with these factors. For example, the competition between technologies and applications, markets, and business models.

This *direction of search* can be described in terms of:

- expectations for the future (incentives, sector growth, technological development)
- policy and regulations
- expectations/demands from main customers
- technological limitations or bottlenecks
- major issues or crises in current business landscape

Entrepreneurial experimentation

Uncertainty is a major feature of a TIS, and a major source of its reduction is *entrepreneurial experimentation*. This consists of testing new technologies, applications and business models. To analyse the state of this function, one may look at the number of new organisations, number of applications, and use of complementary technologies.

Market formation

Markets for products or services generally go through phases. Initially, there is often little or no demand, where potential buyers have not yet expressed their demand (or are unable to do so), the price is not yet satisfactory, or there is too much uncertainty. In the early phases, a "nursing market" may exist. This can then develop into a "learning" stage, where the TIS develops further as can create a "bridging" market. At this stage, production/volume increases and may lead to a mature mass market. Market formation may be analysed in terms of types of customers, their buying patterns, and market size.

Legitimation

This function deals with the social acceptance of a TIS. This can be demonstrated in terms of TIS alignment with (national/regional) legislation, how perception of the TIS influences demand, and the actors that influence legitimacy. Legitimacy can be evaluated by analysing the perception of relevant stakeholders that are involved in the sector, for example through interviews or surveys.

Resource mobilisation

When a TIS develops, a number of difference resources need to be mobilised. These include human capital, financial capital, and complementary assets (products and services which support the main technology, such as infrastructure).

This function can be measured in terms of amount/changes in financial capital (such as investments), amount/changes in human capital (such as skilled workers or university graduates) and the amount/changes in complementary assets.

Development of positive externalities

Positive externalities can be defined as "free utilities". That is, benefits arising from the previous entry of new organisations into the fields. This can result in the improvement of the aforementioned functions, such as *legitimation* or *market formation*. As such, subsequent entries benefit from the work done before them.

Furthermore, having a large and diverse group of organisations or actors in the industry can develop new combinations of actors/technologies. For example, energy storage provided by connecting electric vehicles to the electricity grid. Some ways of quantifying these positive externalities include:

- development of a shared labour market
- development of firms focusing on specialised goods/services
- information flow and knowledge sharing

3.2.4 Assessing functionality and setting process goals

Using the above functions, it may be possible to distinguish whether a TIS is in the formative or growth phase. Furthermore, it is possible to then determine whether the current functioning of the system suits the phase. This can be done through considering:

- time
- uncertainties
- price and performance
- volume of diffusion
- character of demand
- positive feedback and externalities (or lack thereof)

Additionally, comparing the TIS studied with other TISs can be of value. For example, comparing the same type of TIS between different regions. This is however outside of the scope of this study.

3.2.5 Inducement and blocking mechanisms

Inducement and blocking mechanisms can be derived from analysis the TIS through the lens of functions. New TISs are often hindered by established systems - it is therefore important to understand the interaction between them. This can be described using blocking mechanisms - the factors hindering the development of a TIS. This can be described by using the 7 functions mentioned previously, for e.g. legitimation.

Inducement mechanisms are the opposite - factors encouraging the development of the TIS in focus. For example, for renewable energy sources, a policy instrument such as a carbon tax, may be an inducement mechanism.

3.2.6 Key policy issues

Functionality assessment describes the functionality of the system, in terms of achieving its overall goal (remembering that a system is defined as a group of components that work towards a common goal or function). In this part of the process, the identification of policy issues affecting the TIS (blocking or inducing) takes place, based on how the TIS performs. This is relevant to policy makers, as policy can be identified to either remove the blocking mechanisms or introducing/improving inducement mechanisms. These will of course vary per different TIS.

4 Method

This chapter describes the research methods used to obtain and analyse the data required to address the aim and research questions. As a reminder, the aim of the work is to analyse the technological innovation system dynamics of solar PV in Västra Götaland. The research questions was: “What are the technological innovation system dynamics in the Västra Götaland solar photovoltaics sector?”

This is to be done by: identifying the main actors, relations and regulations regarding solar photovoltaics in Västra Götaland, and their roles. Additionally, to determining drivers and barriers affecting the diffusion of solar PV in Västra Götaland.

4.1 System mapping

For the system mapping, the system considered will be the actors, networks, institutions and technologies (Bergek et al, 2008). In terms of actors, networks and institutions, key actors in the solar photovoltaics sector in Västra Götaland were identified. Actors were studied based on their roles, knowledge, and their ability to influence the sector. Additionally, relevant networks were identified largely through stakeholder interviews. For technologies, the present state of the solar photovoltaic system was analysed in terms of regulations, costs, scale of solar photovoltaic uptake, and yearly installation capacity. This was done through literature, such as the Swedish National Survey on PV Power Applications, and interviews that provided most of the material for this process. The role of complementary technologies supporting or related to solar PV was also explored, but not in detail.

Initially, stakeholders were identified using the outcomes from stakeholder dialogues. These stakeholder dialogues took place in the initial stage of the work, as covered in the section *Method for formulating research question*. Following the dialogues, initial stakeholder interviews were performed with selected participants from the dialogues. These interviews served to help identify key stakeholders in the solar PV sector to interview. Based on the outcome of the interviews, a snowball sampling approach was used, with interviewees recommending potential actors to interview. Both private (e.g. installers) and public actors (regional government) were engaged.

Public sector actors in Västra Götaland were identified as being of relevance, due to the geographical scope of the research. Public sector actors were thought to be interested/concerned in the topic, as well as have the ability to influence the local sector. Private sector actors encompass a broad range of the value chain, however, the focus of the interviews was on downstream actors. This was based on the initial interviews, which suggested that the most notable and active sector of the value chain was to be found downstream, with upstream activities (such as cell and module manufacturing and assembly) being quite limited in the region.

4.2 Data collection process

The aim of the interviews was to gain an understanding of the solar PV sector, through stakeholder input. A semi-structured interview process was conducted with the following 13 stakeholders:

1. Director, regional science park
2. Regional Planner, regional municipal association
3. Entrepreneur, private sector
4. Entrepreneur, solar installation company
5. Entrepreneur, solar installation company
6. Researcher, technical university
7. Project Manager, regional energy office
8. Salesperson, local energy utility
9. Researcher, technical university
10. Sustainability Manager, local energy utility
11. Solar PV Specialist, local energy utility
12. Researcher, technical university
13. Energy Manager, large housing company

The interviews followed a semi-structured approach, as this form allows the introduction of new, unexpected topics, providing flexibility. Furthermore a semi-structured approach allows for follow up questions and clarifications.

Due to the use of the TIS approach, an interview template was used. This allowed consistency between the interviews, with questions focused to probe around i) actors, networks and institutions and ii) the 7 functions. With the exception of open-ended introductory and concluding questions, the questions had no sequential order.

Some interviews were conducted in-person, while others were conducted telephonically, due to geographical/travel limitations. Most interviews were recorded (with the interviewees' permission) to aid in subsequent transcription, and hence later analysis of the interviews. 3 interviews were not recorded. The initial two interviews were not recorded as they were mainly for identifying potential interviewees. For the interview not recorded, the recording equipment failed. For these three interviews, notes were taken by the interviewers.

Relating to the interview process: the introductory open-ended questions, were thought to allow the interviewees to feel more comfortable, as well as often directed the interviewers towards the stakeholder's strongest areas of experience or knowledge. This allowed the interviewers to tailor each interview's focus based on the interviewees most relevant area of knowledge or experience. The open-ended concluding question asked the interviewees whether they "had anything else they would like to add" or whether there was something notable the interviewers had missed. This was often useful, as it allowed interviewees to fill in the gaps by expanding on areas of importance that they feel may have been missed or neglected during the interview.

4.3 Interview analysis

The recorded interviews were transcribed and imported to qualitative data analysis software, NVivo 12 Pro. An *a priori* coding (Prochaska, 2013) technique was used, which assigns codes based on existing theory or frameworks. These codes were based on the TIS approach, using the 7 functions defined in the functional analysis as the highest hierarchy. Statements made by interviewees relating to these codes were identified from the interviews. These could then be used to address the research questions based on the TIS framework. Firstly, for identifying key actors, relations and regulations. Additionally, for identifying the drivers and barriers affecting the diffusion of solar PV in Västra Götaland. *A priori* coding was used, as codes could be assigned to the 7 functions to assist with functional analysis, a more deductive research approach (Yin, 2015).

5 Results and Analysis

This chapter presents the results of the work, in the form of interview analysis, through a TIS lens. The results detail the current state of the Västra Götaland solar PV sector, detailing drivers and barriers affecting the diffusion of solar PV.

5.1 Knowledge development and diffusion

Potential customers are generally knowledgeable about solar

The actors found in the Västra Götaland region actively take part in information dissemination activities. On the residential front, there is a variety of platforms targeting information dissemination towards customers. As such, customers are generally well-informed about the practicalities of installing solar PV systems.

These include the activities of a local web-based platform, *Solcellskollen*, which aggregates information about local installation companies. On this platform, potential customers can input their street address and desired solar specifications. The platform then calculates expected electrical output, basic financial information, and a list of potential installers. The web-based platform allows users to review installation companies, and share reviews with potential customers.

Furthermore, this platform produces a podcast, *Solcellspodden*. This podcast is focused on solar PV news and activities, and is supplemented with broad content related to energy, sustainability, and the environment.

However, despite the existence of networks offering practical information, thus assisting with the acquiring of solar PV, there seems to be a lack of knowledge related to standards, and governmental policy and regulations. An interviewee from the private sector said:

"I wouldn't say it's too few people dealing with information, but there are a lot of uncertainties. But that's more on the governmental agency side, like Elsäkerhetsverket, insurance companies, big actors that have different kinds of rules on what you should expect from solar [PV] systems."

In addition, through support of the local energy office, Region Västra Götaland supports networks for information sharing. Such as the municipal network for sustainable development *(Kommunnätverket för hållbar utveckling)* and the Energy and climate advisor network (*Energi- och klimatrådgivarnätverket*). Despite strong communication to customers, communication between companies has been highlighted as comparatively limited, which is thought to be due to companies trying to forge a competitive advantage.

Inadequate intermittency management and energy knowledge

Lack of knowledge with regards to intermittency management and energy storage leads poses barriers to diffusion, particularly among grid operators or large scale utilities. Despite solar PV being a relatively mature as a technology, knowledge around support technologies is thought to be lacking. Interviewed stakeholders cited quick deployment and installation of even relatively large solar parks, with a 5.5 MW plant undergoing completion in approximately a month. However, the maturity of peripheral and complementary technologies has been criticised For example, managing grid frequency fluctuations, resulting from the lack of generator inertia. Furthermore, energy storage during times of excess production has been cited as an issue. These issues are often raised by grid operators, who cite that these issues will have a negative long-term effect on the stability of the electricity system.

However, there is a presence of knowledge development, with some initiatives in the region aimed at addressing this. For example, a vehicle-to-grid (V2G) projects in neighbouring regions, such as Kungsbacka. This project aims at building competence in using electric vehicles as a means of energy storage, with vehicles charging up during periods of low demand, and discharging into the grid at times of high demand.

Research and academia: Current importance appears limited

Most stakeholders consider the current role of academia as limited, in terms of knowledge development for supporting the diffusion on solar PV in the region. Rather, the prevailing opinions are that research is important for the future of the region's industry. As interviewees expressed, the areas of focus are firstly, for intermittency management and storage, once solar has achieved an appreciable grid mix. Secondly for niche applications, such as integrated solar applications. Furthermore, there is also considerable interest in the life-cycle aspect of solar PV panel production. That is, quantifying and understanding the impact arising from production as well as from disposal at the end of life. For example, the impact of obtaining raw materials used when producing solar cells, as well as the largely fossil-based energy consumption during production of panels in East Asia. One researcher remarks:

"What's being talked about now in terms of the environment, is the life cycle perspective, that's what I think is interesting about the research. Besides that, it's becoming more important to see the system perspective. Let's say for example, you have solar on the roof and you also have electric cars, you can use the cars for energy storage."

This implies that a lack of knowledge about system consequences may hinder the diffusion of solar PV, as stakeholders may be concerned about potential negative impacts, such as waste.

Heavy focus on companies downstream in the solar PV value chain

The early stages of solar PV work in Sweden focused most heavily on research and development of solar cell components. As an example, Uppsala University was considered a pioneer in thin-film solar cell technology based on CIGS $Cu(In,Ga)Se_2$. Starting in the 1980's, there was a hope in the research and technology development community that Sweden could potentially become a notable producer of solar PV components in future, particularly based on thin films. The aforementioned Uppsala University research group formed a spin off company, Solibro, which attempted to raise capital for the construction of a commercial-scale factory. However, this failed, resulting in the company being acquired by first a German company, and then later a Chinese company. This is exactly the same case for Region Västra Götaland as well, since there is not a notable production initiative.

Additionally, the nature of the international market - with cheap imports from Asia, makes local producers uncompetitive. Consequently, The Swedish (and Västra Götaland) solar PV sector is currently dominated by companies in the downstream portion of the value chain.

5.2 Influence on the direction of search

Renewable electricity certificates (*elcertifikat*)

As of January 2012, an electricity certificate system (elcertifikatsystemet) has been implemented, incentivising the production of renewable electricity from solar along with wind, some hydro, some biofuels, geothermal, wave energy, and CHP plants running on peat (decayed organic matter). Electricity producers (including private citizens) are entitled to 0.60 SEK/kWh remuneration for electricity sold to the grid, which is a driver for uptake.

However, it is unclear how long this policy measure will remain in place for, though stakeholders indicate that it is likely to remain while solar PV still accounts for a small percentage of total electricity production. A number of interviewees involved in energy utilities, sales, and installation estimate that this system is likely to be cut when solar no longer needs incentives for stimulation. One stakeholder estimated this scheme to be present until solar PV reaches around ~4% of total electricity production. A consultant / sales person remarks:

"You have 60 öre from the state in your yearly [tax] declaration. We don't know how long time the government would like to maintain that support. But we think that if the percentage of solar power installation for generating electricity is below 4% of the total, they need to stimulate the market by doing that."

This uncertainty in the long-term outlook of the certificates has been cited as a barrier.

EU discards Chinese solar panel import tariff

In 2013, the EU imposed tariffs on solar panel imports from China due to the suspicion that the panels were being sold below cost-price, a practice termed "dumping", which was thought to be threatening jobs and negatively impacting European solar panel producers. As of September 2018, this policy has been eliminated, reducing costs to consumers. One stakeholder from a local utility company remarked:

"if you look historically, and the reason that's happened at all is that Germany actually started. They got Chinese producers to ramp up their volume, and when they ramped up their volume, the prices decreased [...] also the [import] tax has been reduced from last year."

The purpose of the tariff was to encourage production of panels within Europe. Locally this has had little effect on module production, as production in the region was absent at the time of introduction and remains so. Thus, this is a driver for the diffusion of solar PV, since prices have decreased, encouraging uptake.

The phasing out of nuclear

On June 10, 2016 Swedish Parliament agreed on a long-term plan for the country's energy system. The agreement targets an electricity supply of 100% from renewables by 2040. The agreement effectively stops the building of new nuclear power plants, with the exception of the addition of a maximum of 10 reactors at already existing sites. Considering that nuclear makes up approximately 40% of Sweden's electricity production, the phasing out of nuclear power will have significant impact on the profile of generation infrastructure.

"There's no decision to phase it out. We have an energiöverkommelse, an energy agreement between all political parties in Sweden [...] the agreement is that by 2040, we're going to have 100% renewable power in power generation. Which excludes, in effect, nuclear, because nuclear is not defined as renewable."

However, there is still uncertainty on how binding the agreement is, with most interviewees signaling significant doubt that it will occur within the targeted time frame. Since there are nuclear facilities supplying the region, such as Ringhals, the local demand for renewable sources is expected to grow to offset the reduction in nuclear power. This is expected to increase the demand for solar in future.

Building permits

Building permits have been cited as a barrier for diffusion, as they are often seen as complex and difficult to understand. Additionally, they differ extensively, even between municipalities.

"*There are things that are local, like building permits. That may be even local, may be more municipal. Some municipalities make it really difficult to put up solar. That's one thing that's quite local.*"

As such, The National Boards of Housing, Building and Planning currently has plans for simplifying the permit procedure on a national scale. A proposal to make the process simpler and clearer has been submitted (IEA, 2019).

Local grid regulations and conditions

Grid regulations and characteristics are highly localised. Grid regulations are often localised down to the street or postcode level, with infrastructure in the area playing a role. For example, if a potential customer has poor transformer infrastructure in their area, they may be required to pay for the cost of upgrading it, before they are allowed to install grid-connected solar.

Additionally, although grid companies are regulated, the grid is most often a monopoly in a region, which limits competition and results in a single organisation having the decision power. As such, grid companies can decide factors such as: meter requirements, as feeding electricity into the grid requires a different type of electricity meter in order to measure the electricity sold to the grid. Additionally, it is the grid operators who set the rules for net-producers of electricity, for example the grid fee costs paid by customers. An employee from a local energy utility mentioned the following implications of grid fees:

"Some of these solutions make it more difficult to run a system-wide grid. Because we're now exaggerating differences in production. A lot of the motivation for solar is that you don't have to pay for your grid tariffs in summer. But of course those tariffs need to be paid, so grid tariffs will go up in winter."

Thus, this is currently a driver for solar PV. However, in future, this is expected to cause an increase in the difference between winter and summer prices., which customers are expected to react negatively to.

Furthermore, transmission grid capacity is limited in some parts of Sweden. That is, it cannot handle an increase in power distribution. For example, this is an issue in the Stockholm/Västerås region in the east of Sweden. According to stakeholders from a local utility, Göteborg Energi, this is not an issue in the greater Gothenburg region. However, in the eastern parts of Västra Götaland, installation companies have mentioned grid instability as an issue they encounter. This may be a driver for solar PV in future, as local production (such as solar PV on commercial/residential property), may limit the requirement for transmission grid capacity.

5.3 Entrepreneurial experimentation

Matching and bundling services

With 2018's solar boom, installed capacity increased by ~70% year-on-year. This led to a significant increase in demand being placed on the regional solar PV industry. Consultants and installation companies report being overburdened with requests for quotations (a price offer for an installation) from prospective clients. For some companies, the burden has become so large that they have either i) started charging for quotations, or ii) focused on particular market segments.

"We have gaps of accessibility for customers [...] Right now the industry has such a heavy pressure that often you have to wait to even to get an offer from the supplier. Some people say they wait for two months. So that means that many customers are prioritised according to what the supplier believes is interesting. Some companies are beginning to charge just to leave an offer."

This has supported the formation of companies that assist with matching customers with consultants or installation companies. For example, new actors such as *Solcellskollen* and *GreenMatch* were described as follows:

"Solcellskollen surely has a role in the industry, they are needed, because there's similar services like them called GreenMatch. They get inquiries from customers and they bundle them together and they see who's really interested, and who's not, and they categorise them"

A rather interesting finding was the emergence of matching services in the solar PV sectors, a form of entrepreneurial experimentation, supporting the PV sector in the region. These services act as middlemen, communicating with the potential customers to figure out their needs, location, roof area, and other pertinent information. Based on the information provided, they then either recommend the client contact a specific company, or send the company a bundle of a number of similar customers (usually based on the types of customers the company prefers). Additionally, these matching services also report acting as a vetting service, attempting to ensure that the installation companies they work with are experienced and provide a high-quality service and installation. The matching services usually charge a commission fee paid by the consulting or installation company, rather than the customer. The formation of these companies has been supported by the recent increase in interest from customers, which has resulted in consultants and installation companies being overburdened with requests for quotations from prospective clients.

Integrated applications

As local manufacturers struggle to compete with high-volume, standardised roof panels imported from abroad, specialisation in applications has been seen. Integrated applications often require tailored design and extensive communication between the customer and supplier. Local knowledge has provided a market gap, giving firms in the region an advantage over international competitors.

"These building elements that you integrate solar cells in, they are subject to different types of regulations that are quite specific. It's more important to have good collaboration between different parts of the value chain. This closeness between the customer and the supplier becomes a lot more important."

In particular within integrated solar cells, applications in rooftop tiles and window panes are emerging locally. As a regional energy office employee said:

"*There are a lot of interesting companies in Sweden that actually have small scale production of other types of solar cell materials."*

For example, the company Midsummer produces flexible panels suitable for these types of applications. Multiple stakeholders expressed their view that this market segment would grow significantly in the coming years.

5.4 Market formation

Subsidy system as a driver for uptake

Currently, there is a subsidy system in Sweden, offering a 20% rebate on residential solar PV installation. As of 2019, the incentive scheme has a cap of 736 million SEK. This is generally a driver for solar PV diffusion, though it is thought to come with some negative conseuquences.

The cap has been seen as setting an artificial limit to the market. Furthermore, the rate has varied in the past, creating uncertainty for those planning investments. In 2018, the cap was

915 million SEK, with a rebate rate of 30%. Since 2009, Energimyndigheten have allocated 3 billion SEK to the program, with rebate rates varying from 20% to 65%.

The expected rise in the price of electricity

An important variable that affects investments is the change in the price of electricity. It is expected by a lot of the stakeholders, that in the next years the trends of increasing electricity prices will continue. Thus, the potential profitability of consumers investing in electricity production from solar PV is likely to improve, which is a driver for uptake. The price of electricity has a big impact on the payback time of an installation, with an increased price leading to a faster payback time. Furthermore, the trading of electricity within a large, interconnected European electricity network could add a further option for those wishing to feed excess energy back to the grid.

Public procurement policies as a driver for diffusion

Public procurement policies can be a driver for the formation of a market. The public sector's procurement policy can stimulate a market and help create some of the demand necessary for the support the growth of an industry.

"These are businesses that employ loads of people, that have a lot of facilities, a lot of housing facilities, for example. And that means that the region could buy solar cells and put them on buses, trams, houses, essentially using public procurement as a policy instrument to influence the PV market, which would also of course in turn then have positive impact on upstream structures in this value chain."

According to the Swedish government, public procurement needs to work in a way to ensure efficiency and compliance with the law and to function within the rules of market competition. However, the broader goal is to promote innovations taking into account the environmental and social aspects. Most stakeholders interviewed believe the regional government serves as an example for society, having established solar PV installations on many public sector buildings roofs starting about 10 years ago. A researcher said:

"*Public procurement can play a very important role in giving the market this extra push to actually make it commercial in the purest sense, in a way that means that it is not dependent on market subsidies nor on the charitable will of individuals and organisations."*

As an example, Region Västra Götaland installed a solar park on the roof of the Skaraborg Hospital located in Skövde. The installation consists of two parts, a roof mounted installation of 332 kW, covering 2 150 m^2. In addition, there is also an installation over the parking lot, covering an area of 500 m^2 and producing 80 kW. At the time of installation, the project was one of the larger ones in Sweden, winning the Svensk Solenergi's 2015 Annual Solar Energy Prize.

"The plant shows how a large public company can pave the way for new technology through a purposeful, long-term and politically-based initiative."

However, some stakeholders also criticised the public procurement process around this, stating that it favoured simply the lowest price bidder, with no consideration of system quality or longevity.

Buying patterns

Regarding the typical PV customer profiles, according to the interviewees they are mainly house owners that install small-scale systems on their property, larger scale installations on commercial or industrial buildings, and also a small number of large-scale solar parks. On a national scale, the distribution of PV system size is U-shaped - meaning that the majority of installation are either very small-scale, or large solar parks. This is generally seen as positive, as development is not limited to a single type of installation.

A saturation of installation companies: a negative effect from subsidies

There is a large number of local installation companies found in the sector. The national industry association, Svensk Solenergi, comprises of approximately 250 members, with the largest group (107) being installation companies, followed by a significant number of consultancy and sales companies.

Many of these installation companies are thought to be inadequately experienced. That is: they are new to the solar PV industry, have installed few or no PV systems before, but are interested in the industry due to its apparent growth.

"[There are a] lot of companies in the market that should not install PV. We have members that belong to the association, they registered a month ago and they don't even have a homepage, they have not installed anything, but they think it is a good business. Same situation with heat pumps 20 years ago, collectors 10 years ago, and so on. The positive thing with the subsidy is that you need it, in order to introduce the technology. If you do it too much then the companies who shouldn't be there join."

They have largely been encouraged to enter the sector by the boom in residential installations spurred on by high government subsidies. Among industry actors, there is the belief that many of these companies install systems of substandard quality. Furthermore, the lack of a third party control/inspection procedure on installations (for safety, quality) is thought to worsen this issue. It is a common occurrence for systems installed to require repair in just 2 or 3 years, despite that solar PV systems are generally designed to last for a minimum of 10-15 years. A possible consequence from this is the negative impact faulty installations may have on the legitimacy of PV. A more effective, on-site inspection mechanism is required to combat this.

Local housing companies

Local housing companies have been identified as having a role, mostly as a large source of potential diffusion. These companies have an abundance of roof space, and the residents in their buildings have significant energy needs. However, there are potential challenges, such as metering infrastructure, which is not suitable for monitoring the energy usage of individual apartments in older buildings. Some of the more notable housing companies and associations includes the likes of Bostadsbolaget, HSB, Poseidon and Västfastigheter.

5.5 Legitimation

Solar generally seen as suitable for Sweden:

In the past, it has often been assumed by the public that solar PV is unsuitable for the region, and Sweden as a whole. This perception is largely based on Sweden's northern latitude, which means that winters are generally dark, with only a few hours of daylight. However, this perception seems to have mostly changed. Many actors think this is due to the German context where solar has been deployed quite extensively. Germany has a similar latitude and geographic (climate) conditions to the southern portions of Sweden, and the general public now generally sees this as a positive example. Common public perception is that solar can work, at least in the southern portions of Sweden, due to international examples of success in similar conditions. An employee from a local utility company reports:

"I think many Swedes always thought that it's not as sunny here. So, 'oh it's so dark, it's dark in the winter, we can't have PV'. But then people started to realise, I mean, they have a lot of PV in Germany and they have sort of the similar amount of sun as we do."

Signaling sustainability: a driver for diffusion

Solar has become a way for companies (or individuals), to signal their sustainability commitment to others. Installing solar PV, or purchasing electricity generated by it, is often seen as a way to do this. An energy utility employee reports:

"PV comes into it as a part of that discussion, it's a very symbolic form of engagement currently when it comes to sustainability […] it oftens comes up as a natural part of discussions with customers […] the question would immediately pop up: 'can we buy PV from you in some way?', because everyone wants to have that in their communication."

Additionally, solar's legitimacy is often used in marketing as a means of reaching potential customers, even for applications that are somewhat removed from solar PV itself. A member of the board of a housing association recounts:

"I was invited by [utility company] for a solar power evening. It was really fascinating when I came there because they hardly spoke about solar cells. 90% of the evening, talks and

discussions, was about district heating. What they did was to invite people using the legitimacy of solar cells, but what they really wanted to do was to sell services related to district heating."

Ensuring sustainability

One of questioned aspects of solar electricity, is being whether it is as clean as wind power for example, or not. The locally produced photovoltaics follow the Swedish production standards, however, the majority of the panels sold in Sweden and in the region are imported from Asia. Initially, they were imported by Germany, then China and nowadays from south-east Asian countries, like Malaysia. The production methods are different there, and involve a lot more carbon emissions during production. This can compromise the carbon neutral nature of this renewable energy and reduce the incentives to aim for it nationally or regionally. One of the main motives mentioned was the environment, aside from the economic incentive or the energy security. If this is negated the sector may lose legitimacy, so this can become a potential barrier.

Information sharing and marketing: a way to improve legitimacy in the region

Information sharing (and marketing) by local companies contribute, besides knowledge diffusion, also to legitimation of solar PV in the region. As part of the entrepreneurial activities, local actors often branch out and form side-projects focused on interfacing with the public.

"You have people who do podcasts. I wouldn't say it's a typical business idea, it's more of a brand-building thing, marketing. The people who do these podcasts, they are in the industry somehow, they already have a position somewhere."

"Then we have the consultants within the industry, that work with just having presentations. People pay them to come and to inspire people to work with solar."

These activities often involve into social media presence, podcasts, and lectures with the initial aim being informing - but ultimate aim of marketing to customers in order to stimulate business.

Industry associations' role in improving solar PV legitimacy

Furthermore, the work of industry associations and lobbying groups further drives legitimacy. Svensk Solenergi, the national industry, have 2 full time employees and place their focus on lobbying to politicians. They articulate the needs of companies in the solar sector and increase political legitimacy, and try to influence policy makers.

5.6 Resource mobilisation

Difficulty employing skilled full-time staff

The work year for many solar installation companies is often shorter than other industries. For example, the installation of solar PV systems is often difficult between the months of November and February. This is because of the presence of ice and snow on roofs, which due to safety considerations, may lead to a delay of construction. Furthermore, there is often a reduced workload around spring time, due to Easter holidays. A member of a private company stated:

"Maybe 5 months [of the year] the employees can go out there and work. But you have pay him 12 months. So if you employ people for 12 months all the time, it's very difficult to be the cheapest one"

As such, it may be financially impractical to employ full time staff. Some companies then choose to only have a minimum number of full-time employees who work as project leaders, while employing shorter contracts for the rest of the employees. This may discourage skilled workers from choosing this occupation over similar work.

Furthermore, the most desired employees are those with electrical experience, such as electricians. However, recruiting them is often difficult as they generally have access to employment with safer (no working on roofs at heights) and more comfortable (indoors) working conditions. A lack of the appropriately-skilled staff may affect the quality of the installations.

However, the trends have shown increased number of solar labour with the years passing even though the local solar production of solar cells collapsed after 2010. The question is whether this increase conforms with the increased demand in PV installations and whether it can be a self sustained occupation, since operational flexibility to demand is sought from the installation companies to reduce their costs.

5.7 Development of positive externalities

Taking advantage of others' learnings

One of the main barriers for technological development in an emerging sector is usually the research cost, and costs inherent in progressing along the learning curve. However, in this particular case, Sweden and Västra Götaland specifically, can take advantage of this learning, which has already occurred in other regions. Governmental support for solar cells led to an increased installation rate, large volumes of solar cell imports, and falling prices. This early market creation, pushed by the will of their government to replace coal and nuclear, helped rapidly drive down prices for solar PV installations, largely due to low cost Chinese imports. This can be taken advantage of by the Swedish sector, as the market formation in other regions, Germany for example, means Sweden has the benefit of a cheaper, more mature technology in the local sector's early market stages, without investing themselves.

6 Discussion

This Chapter relates the Results to the established Background, Aim and Research Questions. Reflections are made concerning the Method and limitations of the study.

The aim of this thesis was to analyse the innovation dynamics of solar PV in Västra Götaland. By using the TIS framework, the analysis consisted of identifying the key actors in the solar photovoltaics sector in Västra Götaland, and investigating the drivers and barriers affecting solar PV diffusion in Västra Götaland. In that sense, it is a localised study that analyses the current West Swedish situation, connecting it to some overarching, national factors.

6.1 Contribution of Method

TIS provided to the research an analytical framework for the studied TIS by providing guidance for a structural and functional analysis. This also helped with the formation of the interview guide as well and even more in the analysis of the interview results. As such, the TIS framework served as a good basis. It allowed for the analysis of relevant actors, networks and institutions: this helped address the first research question. Additionally, TIS functional analysis allows the identification of drivers and barriers, through the identification of strong (well-functioning) and weak (badly-functioning) functions. TIS has the potential to deal with institutional strategies. However, TIS considers actors as part of the system itself, and does not draw a strict distinction. However, it has been challenging to account for external factors to the regional context of the technological system.

As to the combination of the two concepts of backcasting and TIS, it was thought that they served in a complementary manner. Backcasting was used to frame a desirable future, and analyse present gaps in the current situation (steps 1 and 2). TIS served as a means for identifying leverage points and creating strategies for addressing them. This was done through analysing strong and weak functions, identifying drivers and barriers, and proposing recommendations based on this.

In the early stages of the work, multilevel perspective (MLP) was used. As such a consideration of using a combined TIS-MLP approach was made. Though promising, the TIS-MLP combination is considered to not yet be well-refined and hasn't been applied to many empirical cases. It is thought that future work combining the two should be clear in its conceptual basis, as well as be performed in a matter that systematically explore the benefits and drawbacks of integrating the two frameworks (Markard and Truffer, 2008). Due to the ability of TIS to adequately analyse the system at hand, and the potential challenges of combining the methods, this integrative approach was not used.

6.2 Discussion of actors identified

With regard to the first research questions, some of the key actors identified in this work include: installation companies, the industry association, the regional energy office, local utility companies, and housing companies. These findings agree with Palm (2016), who identified the key actors as utility companies and local organisations promoting solar PV. The work also agrees with Marklund & Ramberg (2018), who identified 7 such types of actors. However, a major difference to Marklund & Ramberg includes the identification of supply or demand side actors. In this work, supply side actors (such as consultants, energy utilities, installation companies) were more prominent. Conversely, Marklund & Ramberg placed more emphasis on the demand side, citing the importance of customers, such as homeowners and commercial businesses.

As mentioned in the Background, local citizens, who are often prospective customers, have also played a significant role in the industry. Most notably, as a catalyst for the establishment of the largest solar park in Sweden, Nya Solevi. This was started through a local citizen proposal initiative leading to a solar park where citizens are able to invest even if their residence is unsuitable for solar. This initiative received considerable support from the local energy utility, Göteborg Energi, who have also been identified as a key actor.

The actors identified in this study focus mostly on the demand-side of the sector. Identification of supply-side actor could be performed, though these are thought to be limited in the region.

6.3 Drivers affecting the uptake of solar PV

One of the most notable drivers for the diffusion of solar PV was found to be the high legitimacy of solar among the general public and potential customers. Solar is perceived as a symbol for sustainability with companies (or individuals) using it to signal their sustainability commitment. In fact, solar is often used as a marketing tool by companies to sell other, unrelated products. It can be acknowledged that as most of the interviewees were in some way affiliated with the solar sector, it is likely that their perception of solar PV's legitimacy could be biased towards that of a strong legitimacy. However, this strong legitimacy finding is supported by the existing literature, which shows that 80% of the general public have a positive view of solar (IEA, 2009). Additionally, Palm (2015, 2016) and Marklund & Ramberg (2018) cite high legitimacy (or *public image*) as a driver for the uptake of solar PV. Thus, the perception of legitimacy in Västra Götaland mirrors that found in the rest of Sweden.

Public procurement policies is seen as a driver for the formation of a market. The public sector's procurement policy can stimulate a market and help create some of the demand necessary for the support the growth of an industry.

It is expected that the trend of increasing electricity prices will continue. Thus, the economic viability of investing in electricity generation from solar PV is likely to improve, which acts a driver for uptake. Furthermore, the removal of solar module import tariffs from China has decreased capital costs, also acting as an economic driver for uptake.

Government subsidies in the form of a capital rebate, as well as green electricity certificate are currently a major driver for diffusion. The subsidy is thought to have been a large part of the rapid rise in installations on Sweden in 2018, with capacity increasing ~70% year on year. Due to political reasons (the time taken to form a coalition government) the subsidy was uncertain for a period of time. However, its reinstatement has restored customer confidence to some degree. In comparison, according to Marklund and Ramberg (2018) major drivers encouraging the uptake of solar were found to be financial reasons, environmental reasons, projecting a sustainable profile (for example, for marketing reasons). Entrepreneurial experimental and positive externalities were also found to be drivers by those authors, as was found in this study too, with the identification of matching/bundling service companies. Furthermore, integrated applications and niche solar often require tailored, custom solutions. Local knowledge has provided a market gap, giving firms in the region an advantage over international competitors, acting as a driver for the upstream portion of the sector.

Self-sufficiency as a driver has also highlighted as a driver by previous literature (Aguilar, 2013). For consumers, producing one's own electricity with solar PV is sometimes seen as a way decrease dependence on the grid and market prices. However, this was not found to be a major driver, in the region.

6.4 Barriers affecting the uptake of solar PV

As mentioned, knowledge *sharing* among stakeholders is generally strong. However, there is a perceived lack of knowledge *development*. This has generally been cited around the areas of intermittency management and energy storage. Some grid operators still perceive solar as a threat to the long-term stability of the electrical grid, due to a lack of technologies to manage intermittency and solar's effect on electrical grid frequency. This agrees with previous literature, which cites the "intermittent nature of solar energy production" and "solutions for the storage of energy produced by solar" as barriers (Marklund & Ramberg, 2018).

Among installation companies, a lack of solar PV-specific installation best-practice and safety standards was highlighted as barriers. This, combined with a lack of independent safety inspections, is thought to lead to a notable number of PV installations being of substandard quality. Furthermore, this has been linked with insurance companies, where very few insurers are adequately knowledgeable on solar PV to provide insurance on the systems.

In terms of resource mobilisation, human capital has been highlighted as a barrier. Solar PV installation companies often experience great difficulty employing skilled, full-time staff. This is due to two reasons. Firstly, the short work season (due to safety concerns in winter conditions, as well as holidays) means that employing staff for the full 12 months a year when work generally only occurs for ~6 full months is costly. Secondly, the most desirable employees are those with electrical experience, such as electricians. However, recruiting them is a challenge. These workers generally have access to employment with safer and more comfortable conditions. This finding appears to be novel, and has not been encountered in previous Swedish literature.

6.5 Limitations of the study

One of the main limitations that was faced in this study was that although TIS served its purpose quite well with analysis, some findings couldn't be clearly assigned to a single function. For example the focus on the downstream part of the value chain that has been observed has both a knowledge development aspect as well as a market formation one. One reason for this may be that functions within a system interact with, and affect one another (leading to positive feedback, for example). This is a known limitation of static (with respect to time) TIS analyses, such as this one, and has been pointed out in previous literature. This phenomenon is called cumulative causation, and can be addressed by mapping events in sequence, a process known as *event history analysis* (Suurs and Hekkert, 2009).

Furthermore, a language barrier may have existed between the interviewers and some of the interviewees. All the interviewees were conducted in a common language, English. However, some translation had to be performed from Swedish to English. This was mostly for proper nouns (company, organisation, network names) without an English equivalent. However, some technical concepts were translated too. It is important to note that this may lead to some loss of *conceptual equivalence*, which has been reported in literature dealing with cross-language qualitative research. However, this is generally an issue when the interviews are conducted in another language, with the use of a translator or interpreter. The use of a common language between participants and researcher (as in this study) is thought to minimise this issue (Squires, 2009).

Regarding data, a lot of the focus of literature and research is on a national level, but there is little to be found on the regional level. Thus, the background information for Västra Götaland was limited by this.

7 Conclusions and Recommendations

During the early stages of research, it was found that there are drivers supporting the diffusion of solar PV in Västra Götaland. However, there are also barriers that must be addressed in order for these drivers to effectively spur on the industry.

The regional energy agency, Energikontor Väst, was identified as coordinating a regionally-focused solar PV project, Sol i Väst. This work is financed by the regional government, Region Västra Götaland, and is aimed at facilitating the diffusion of solar PV in the region. Additionally, the regional government is seen as playing a role through the use of its public procurement policy to support market formation in the early stages.

Notable drivers identified were the strong legitimacy of solar PV, strong knowledge diffusion, capital subsidies, renewable electricity certificate, and positive externalities from other places. Notable barriers identified include: difficulty in employing skilled full-time staff, and long-term uncertainty regarding both subsidies and renewable electricity certificates.

In order to support the further development of the photovoltaics sector in the region, a direction of focus and stimulation of work towards niche applications, particularly building-integrated applications of solar PV could be performed, even at the regional level. This could be performed through a niche application focused network, perhaps as part of the existing local solar PV networks. Additionally, to address the lack of human capital, the regional government could investigate the training programmes for workers, equipping them with the sought-after skills required for solar PV installation roles.

On the national level, to address the uncertainty related to subsidies and renewable electricity certificates, a clear long-term plan for incentives could be implemented by national government. For example, a clear, well-communicated plan for subsidy reduction over time. This would allow more informed financial planning, and make project economic feasibility more secure.

8 References

1. Deutsch, M. (1962). Cooperation and trust: Some theoretical notes. In M. R. Jones (Ed.), *Nebraska Symposium on Motivation, 1962* (pp. 275-320). Oxford, England: Univer. Nebraska Press.
2. Kleinbaum, A. and Tushman, M. (2007). Building bridges: the social structure of interdependent innovation. *Strategic Entrepreneurship Journal*, 1(1-2), pp.103-122.
3. Vergragt, P. J., & Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue.
4. Dreborg, K. H. (1996). Essence of backcasting. *Futures*, *28*(9), 813-828.
5. Broman, G. I., & Robèrt, K. H. (2017). A framework for strategic sustainable development. *Journal of Cleaner Production*, *140*, 17-31.
6. Holmberg, J. (2014). Transformative learning and leadership for a sustainable future: Challenge Lab at Chalmers University of Technology. In *Intergenerational learning and transformative leadership for sustainable futures* (pp. 68-78). Wageningen Academic Publishers.
7. Larsson, J., & Holmberg, J. (2018). Learning while creating value for sustainability transitions: The case of Challenge Lab at Chalmers University of Technology. *Journal of Cleaner Production*, *172*, 4411-4420.
8. Holmberg, J. (1998). Backcasting: a natural step in operationalising sustainable development. *Greener management international*, 30-30.
9. Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E. F., ... & Nykvist, B. (2009). A safe operating space for humanity. *nature*, *461*(7263), 472.
10. United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. *Resolution adopted by the General Assembly*.
11. Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary educational psychology*, *25*(1), 54-67.
12. Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, *31*(8-9), 1257-1274.
13. Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological forecasting and social change*, *72*(6), 681-696.

14. Sandow, D., & Allen, A. M. (2005). The nature of social collaboration: how work really gets done. *Reflections: The SoL Journal*, *6*(2-3), 2-3.
15. Argyris, C. (1976). Single-loop and double-loop models in research on decision making. *Administrative science quarterly*, 363-375.
16. Meadows, D. H. (1999). Leverage points: Places to intervene in a system.
17. Wendelheim, A. (1997). *Effectiveness and process in experiential group learning: comparing a process-directive encounter group (PEG) and a self-directive study group (SSG)* (Doctoral dissertation, Stockholm University).
18. Crane, A., & Livesey, S. M. (2003). Are you talking to me? Stakeholder communication and the risks and rewards of dialogue. *Stakeholder communication and the risks and rewards of dialogue*.
19. IEA (2018). *Renewables 2018: Analysis and Forecasts to 2023*. [online] International Energy Agency, p.3. Available at: https://webstore.iea.org/download/summary/2312?fileName=English-Renewables-2018-ES.pdf
20. Bellini, E. (2019). *Sweden installs record 180 MW of solar in 2018*. [online] PV Magazine International. Available at: https://www.pv-magazine.com/2019/04/03/sweden-installs-record-180-mw-of-solar-in-2018/
21. Swedish Government (2016). *Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats*. [online] Stockholm: Government Offices of Sweden. Available at: https://www.government.se/49d8c1/contentassets/8239ed8e9517442580aac9bcb00197cc/ek-ok-eng.pdf
22. Swedish Energy Agency & NVE (2017). *The Norwegian-Swedish Electricity Certificate Market: Annual Report 2016*. [online] Energimyndigheten & Norges vassdrags- og energidirektorat. Available at: https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=5676
23. Lindahl, J. (2017). *National Survey Report of PV Power Applications in Sweden 2016*. IEA-PVPS.
24. Swedish Energy Agency (2019). *Stöd för installation av solceller*. [online] Energimyndigheten. Available at:

http://www.energimyndigheten.se/globalassets/fornybart/solenergi/manadsrapporter/2019/manadsstatistik-solel_maj19.pdf

25. Porsö, J. (2008). *The effects of a Swedish investment support for photovoltaics on public buildings*. Gothenburg, Sweden: Chalmers University of Technology.
26. Marklund, R. and Ramberg, C. (2018). *When Comes the Sun? A Study of Stakeholders, Driving Forces and Future Scenarios of Solar Power in Sweden*. Lund, Sweden: Lund University.
27. Aguilar, L. (2013). *Solar energy in Sweden: an implementation plan*. Lund: Lund University.
28. Palm, A. (2016). Local factors driving the diffusion of solar photovoltaics in Sweden: A case study of five municipalities in an early market. *Energy Research & Social Science*, 14, pp.1-12.
29. Palm, A. (2015). An emerging innovation system for deployment of building-sited solar photovoltaics in Sweden. *Environmental Innovation and Societal Transitions*, 15, pp.140-157.
30. E.ON (2016). *Svenskarna tror på solrevolution*. [online] Available at: http://www.mynewsdesk.com/se/pressreleases/svenskarna-tror-paa-solrevolution-1421870
31. Hedberg, P. and Holmberg, S. (2017). *Svenska folkets åsikter om olika energikällor 1999 - 2016*.
32. Lazard (2018). *Levelized Cost of Energy Analysis 12*. [online] Available at: https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf
33. Swedish Energy Agency Statistikdatabas. (2019). *Nätanslutna solcellsanläggningar, antal och installerad effekt, 2016-*. [online] Available at: http://pxexternal.energimyndigheten.se/pxweb/sv/N%c3%a4tanslutna%20solcellsanl%c3%a4ggningar/-/EN0123_2.px/?rxid=5e71cfb4-134c-4f1d-8fc5-15e530dd975c
34. Reuters, 2017. *Progress too slow on global goals for sustainable development, U.N. says*. [Online]Available at: https://www.reuters.com/article/us-un-globalgoals-progress-idUSKBN1A22A2
35. Holmberg, J. & Robert, K. H., 2000. Backcasting — a framework for strategic planning. *International Journal of Sustainable Development & World Ecology*, 7(4), pp. 291-308.

36. Holmberg, J. & Larsson, J., 2018. A Sustainability Lighthouse—Supporting Transition Leadership and Conversations on Desirable Futures. *Sustainability,* 10(11), 3842.
37. Brundtland, G.H., Khalid, M., Agnelli, S. and Al-Athel, S., 1987. Our common future. *New York*.
38. Bergek, A. et al., 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy,* Volume 37, pp. 407-429.
39. Mazzucato, M., 2018. *Innovation system: from fixing market failures to creating markets,* s.l.: Revista do Serviço Público.
40. Suurs, R. A. A. & Hekkert, M. P., 2009. Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands. *Technological Forecasting and Social Change,* 76(8), pp. 1003-1020.
41. Squires, A., 2009. Methodological challenges in cross-language qualitative research: A research review. *Elsevier*, 46(2), pp. 277-287.
42. Markard, J. & Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy,* Volume 37, pp. 596-615.
43. Prochaska, F., 2013. *Qualitative Data Analysis.* [Online] Available at: http://www.sjsu.edu/people/fred.prochaska/courses/ScWk242Spring2013/s2/Chapter-17-Qualitative-Data-Analysis_242-Session-2.pdf
44. Yin, R. K., 2015. *Qualitative Research from Start to Finish.* New York: The Guildford Press.

9 Appendices

9.1 Appendix A: Interview Guide

General Questions

- What is your role in the company?
  - Daily duties?
  - Connection with sustainability?
- What is your familiarity with sustainability and regional goals?
  - What is their contribution as you perceive it to the solar sector?
- Do actors in the industry share information and knowledge?
  - If so, how?
- Are you aware of any new business (model) ideas in the solar sector?
  - Do you know any plans (from your department or others) for implementing any of them?
- Where do you think is the biggest market for solar?
  - Residential? Industrial? Utilities?
- Do (potential) customers see solar as a viable solution?
  - If not, why not?
- How do you think VGR can contribute to the transition?
- *A question about the motivation behind solar initiatives (intrinsic/extrinsic)*
- Do you feel like adding anything else that didn't come up in the interview?

Questions based on TIS

1. **Knowledge development and diffusion**

- Applications of technology?
- Areas of knowledge required?
- Which actors contribute to research / sharing information? Where did the knowledge come from?
- Employee competence / knowledge?
- Any problems arising from lack of knowledge? What knowledge is missing?
- Technological learning or experience curve?

2. Influence on the direction of search

- Why did you/current actors enter sector?
- Why have others not entered?
- What do you think is the potential for the sector?
- Trends that may affect the sector's development?
- Current price, and performance of solar? Comparison with alternatives or competition?
- What is the effect of legislation or policy?
- Are there any bottlenecks? Technical or other?
- Which actors are investing in what? What drives different choices?
- What alternative markets, technologies exist? Who is involved in those sectors? Which solutions for which sectors?

3. Entrepreneurial experimentation

- How many new establishments / organisations / companies? What is their background?
- How "wide" is the range of experimentation? In terms of technology, applications and products.
- What has your organisation experimented with? Business models? Services? Products?

4. Market formation

- Who buys the products, services? Is it clear what they want? How do you know what they want?
- What are the incentives for buyers?
- Are there middlemen or intermediaries?
- How has the market developed or evolved over time?
- What drives the market? Have the drivers changed over time?

5. Legitimation

- Which legislation affects the sector? Does it fit needs? Does it hinder development?
- Standards for products or technicians?

- Visions and expectations for industry?
- Are there official meetings, conferences, workshops?
- Is it seen as “okay” to invest in the sector?
- How is the sector represented by the media?
- Are there lobby groups? Are they respected?
- Are there competing sectors? What is the power dynamic / relationship?
- Are there actors who oppose the sector?

6. Resource mobilisation

- What financial resources are there? What type? Grants, loans, venture capital, sales proceeds?
- What are the main skills & competence required? Are they available? In what foms?
- What skills are missing?

7. Development of positive externalities

- What specific investments have been made? By whom?
- What types of uncertainties exist? Why?
- What would reduce uncertainty?
- Are there specialised roles, links in the value chain that support the entire system, that the system depends on?
- Are there forms of specialised labour?

9.2 Appendix B: Phase 1 Background

9.2.1 Sustainability transitions

There is a plethora of different challenges that affect the world today. These include human-caused climate change, resource depletion and distribution, disturbance of natural cycles and biota, as stated by the Global Change Research program and by the Paris Agreement in 2015. To address these challenges, potential solutions can be complex, having the added burden of adjusting to an already existing system, formed on past principles and knowledge. However, there is a rising pressure from the public to change or transform systems and habits. Greta Thunberg stated with the occasion of the climate change conference (COP24) in Katowice, 2018 *"if solutions within the system are so impossible to find, maybe we should change the system itself "*, encompassing in a sentence the school movement for the climate that has risen this last year across Europe which is tightly connected to the radical and in-depth changes that institutions and structures demand to be in alignment with the global goals.

There is a substantial improvement in different sectors, like factory emissions or recycling or renewable energy, mostly in the developed world. As stated by the International Energy Agency in 2018, renewables will be the fastest developing electricity sector, providing roughly 30% of the power demand in 2023, compared to 24% in 2017. However, the positive effects from those changes are generally limited, both because they try to improve existing systems, and also because they act sporadically, like many small scale applications with limited interaction in their designing. Grasping the interdependence within societal functions and systems (Deutsch, 1962), is an important first step towards creating sustainable systems from scratch (Kleinbaum and Tushman, 2007).

This thesis will take a small part of the focus, in this case, the energy sector and try to incorporate the multi-stakeholder aspects into the mapping and planning for the desired growth in the renewable energy sector.

9.2 Solar photovoltaics background

Since the ancient times, humanity has been using solar power with various, continuously improving methods. Currently, some of them are solar heating, solar thermal electricity and the more widely used (for electricity production) solar photovoltaics (PV). Solar PVs were first built in 1883 by Adams and Day, 44 years after Becquerel discovered the photovoltaic effect. Initially the effort was concentrated on increasing their efficiency since their application was mainly for space programs. However, after the oil crisis and the beginning of environmental awareness, new alternatives, preferably cleaner, for energy production were sought after. This led to increased research in photovoltaic cells and programs that led to their cost reduction (Singh, 2012). The cost has been significantly brought down to the point where comparisons with other electricity production methods can be relevant.

A modern photovoltaic solar system consists of:

- *Photovoltaic modules*, the main part of the solar cells. They can be mono-crystalline, polycrystalline or amorphous silicon solar cells.
- *Junction box*, either to connect with the power converter either with the utility system.
- *On-grid inverter*, that converts power from DC to AC.
- *AC disconnect & main panel* that separate the PV system from the electric grid.
- *Net meter*, that monitors the flow of electricity
- *Electrical grid*, is the power network that takes energy from the production place and gets it to be consumed.

(Subathra et al., 2018)

Some other useful terms that could be of importance for the readers of this thesis are:
Capacity factor which gives the amount of energy produced by a plant in comparison with the maximum output, shown as a percentage of actual energy production (NREL, 2013).

Power generation is according to OECD: '*Electricity generation is defined as electricity generated from fossil fuels, nuclear power plants, hydro power plants (excluding pumped storage), geothermal systems, solar panels, biofuels, wind, etc. It includes electricity produced in electricity-only plants and in combined heat and power plants.'*

PV system capacity is measured as DC rating and AC rating (AC is always smaller). This happens since PV modules produce direct current voltage which is then converted to alternating current with some losses included (NREL, 2013).

9.2.2 Background on solar energy in Västra Götaland

Västra Götalandsregionen has been one of the most progressive in the effort against climate change, with stricter goals than the EU, grouped in a vast goal called Klimat 2030. The main categories of focus are: smart buildings, food and health, mobility and renewable/resource efficient goods and services. Besides smart buildings, Challenge Lab addresses these areas. However, it has been identified that one key source of emissions is absent from the targets; energy. It is missing mainly because it is involved in all 4 categories in larger or smaller extent. However that makes it less concrete and thus deters from organised planning for energy transition in the region on a large scale.

Renewable energy is promoted more and more to combat CO_2 emissions. Specifically, solar energy has seen a rapid decrease of its cost to a point where it is half of electricity from coal. However, these studies do not include the storage cost of solar energy which solves the variability of production, the main hindrance for solar to rise to the regime in the majority of regions in a global scale. Some small scale projects are taking place in the region (for example initiatives like Sol i Väst), however the actors and the projects are all small and thus difficult to find a big initiator of change. Communication and collaboration are also serious issues due to the fragmentation.

9.3 Aim and Research Question

The aim of this thesis is to (i) identify and map the key actors in the solar photovoltaics sector in Västra Götaland, (ii) determine the level of maturity of the solar PV sector and (iii) investigate the drivers and barriers affecting solar PV diffusion in Västra Götaland.

The main research question of the work is: "What is the role of the key regional actors in supporting the uptake of solar energy in Västra Götaland?"

The objective behind the question is to describe why the uptake of solar PV has been limited in Västra Götaland. It is expected that through understanding the role of actors, barriers and enablers, it is possible to identify points of intervention. These interventions may be used to facilitate improved maturity and uptake of solar PV.

The research question thus consists of the following questions:

1. Which are the main actors, relations and regulations regarding solar photovoltaics in Västra Götaland, and what are their roles?
2. What is the current level of maturity of the solar PV sector?
3. What are the main drivers and barriers affecting the diffusion of solar PV in Västra Götaland?

9.3.1 Scope

This study will focus on the production of electricity from solar PV in Västra Götaland. Reference will be made to other areas of Sweden, as well as other countries such as Germany, using the same theoretical approach.

The actors that are needed for the targeted map are located within Västra Götaland. However, some institutions outside of the West Swedish boundaries that can influence actor relations within Västra Götaland (e.g. legislation) are also considered. Time-wise, the focus is on the last decade for the main actors, projects and plans. For future plans, the next decade is considered, since Klimat 2030 and its related efforts are to be concentrated during this timeframe.

Qualitative tools were the majority of the tools that were used, since the mapping and the resulting actors and relations are not only easier described this way but also more precisely. Specifically, the tools used were stakeholder dialogues, literature, interviews and workshop was also planned to be included as well. A detailed description of these follows in the method chapter.

Last but not least, technology-specific aspects were not the main focus, it was rather the relationship between the different stakeholders involved, and the means of transition (arenas, financers, initiators). This served not only our aim better but also it was closer the stakeholders' interests as well.

9.3.2 Thesis Outline

To help the readers, the work in this thesis is presented in two stages: Phase 1 and Phase 2. Phase 1 lasted 4 weeks and involved tasks that range from bonding and common basis formulation to information gathering and pair formation. The goal of that phase was to formulate a topic per group that would be in alignment with their interests and ambitions to contribute to sustainability transitions. Phase 1 included defining a framework a sustainable future, description of current systems and envisioning a future situation.

Phase 2 started after groups and topics had been shaped and was the dispatching part of the thesis research and writing. It included data gathering through interviews and literature, and an analysis and presentation of results.

9.4 Method

9.4.1 Prior to Phase 1

Three stakeholder dialogues were held in the study period preceding the start the thesis project, with the topics of Health and Food, Mobility, and Energy, Resources and Materials.

9.4.2 December 2018 stakeholders:

Health and Food: Innovation Management and Communication Group, AllAgeHub, Chalmers Innovation Office, Cairy, ThinkPoint, Stadslandet, Länsstyrelsen Västra Götaland, *Hushållningssällskapet*

Mobility: Gothenburg Region of Local Authorities, Göteborg Energi, Lindholmen Science Park, Johanneberg Science Park, West Sweden Tourist Board, Västra Götalandsregionen

Energy, Resources, and Materials: University of Gothenburg, Chalmers, Göteborgsregionen, Lidköping Municipality, Nudie Jeans, Göteborgs Stad, Stena Recycling

9.4.3 Phase 1

Here the report will number the different steps that were followed during the first four weeks of the Challenge lab master thesis in a chronological order. This does not imply that it was a linear process; on the contrary it was iterative and required a lot of reflection after some steps to digest the intense and fast-pacing process. The steps will be linked to the corresponding backcasting steps as explained in the theory chapter to make the connection with theory more clear.

Step 1 - Define a framework for a sustainable future

Personal values and mission statement

Coats of Arms

The goals of Phase I included the students "feeling ownership" of the thesis project, as well as forming a basis for further teamwork. The definition of personal values and missions statements was a part of this. One of the initial steps of this process was the creation of personal Coats of Arms, where students described themselves visually, and explained their drawings to another group member. The member who received the explanation then shared it with the rest of the group.

Personal Values

The next exercise consisted of defining personal values. Students were given a list of values and asked to pick several that they felt were important to them - it was also possible to define one's own values that were not on the list. Students then split up into groups of three and took part in a telling-listening-observing exercise. During this exercise, one of the three students was the "focus person". The focus person spoke about why those values were important to them, and shared relevant personal experiences and stories related to this. The focus person had 15 minutes to do this. The listener had the objective of listening actively with presence - that is, listen to feel. The listener was instructed not to ask questions, unless the examples used were too vague, and further clarification was necessary. The observer was there simply to observe and keep track of time, without asking questions or commenting. The observer may pick up on non-verbal cues, and also helped to ease the tension during the exercise.

The personal values exercise draws from Wendelheim (1997), which states that trust and openness are required for tasks with high complexity. Furthermore, Sandow and Allen (2005) emphasise the role of listening, observing, understanding and trust in enabling collaboration. This type of collaboration can lead to increased participation, creativity and innovation. A lack of trust has negative consequences, such as social separation, redundancy and increased costs.

Strengths

The strengths exercise consisted of students dividing up into groups of three. In these groups, each student wrote three strengths they saw in the other two students. The students then shared their perceived strengths with one another.

Weaknesses

Students were asked to reflect on where their strength/weakness focus is - whether they focus on using their strengths, or being conscious of their weaknesses. A further exercise was done, where weaknesses were identified based on balancing strengths. This involved identifying what would happen if a strength was perceived as being exaggerated. This "overdone" strength was then contrasted with its complementary strength - a way of considering how to balance it. The complementary strength was then also considered in terms of what would happen if it was also overdone - leading to the polar opposite of the original strength.

Mission statement

The mission statement was defined as “a statement of your personal purpose, reflecting your personal values and principles (for sustainability)”. An example of this was presented in the form of a Howard Behar clip. Students then reflected individually by comparing their personal values with the group-defined sustainability principles. Students then reflected upon this in pairs, and then as an entire group. As this process takes time, up to several years, students were encouraged to work further on developing a mission statement over the course of the thesis.

Sustainability principles

In the backcasting approach, a desirable future is defined. This is done by defining a set of principles that apply to a sustainable society. Four aspects are considered: well-being, social, economic and ecological. The pillars of sustainability that were used in the theory took the shape of a lighthouse that will be created by students to guide them as the process unfolds. Of course, the principles were arrived at by consensus of the group.

Figure 5: The sustainability lighthouse adopted from Holmberg and Larsson, 2017

Systems mapping

As part of the backcasting process, describing the state of the current system is required. This was done to obtain a preliminary understanding of the current system. This included: Identifying challenges, current projects and processes or *“seeing the whole system”*. Seeing where the potential lies - in order to *“intervene where the leverage is high”*. Furthermore, addressing the core of the problem: "solving the right problem", addressing it at the root, and attempting to be aware of mechanisms that may be hidden.

Additionally, the systems mapping served as preparation for the stakeholder dialogues. It served as a basis for enabling an informed dialogue, and also provided an initial map that could be confirmed, denied and/or expanded upon by the dialogue participants. The systems mapping was done using a visual approach, describing the current system of the three thematic areas. The three thematic areas were (Health) and Food (the Health aspect was later dropped), Mobility, and Energy, Resources & Materials. The mapping employed took on a multilevel perspective, with actors and processes being mapped on the niche, regime and landscape level.

Step 2 - Describe the current situation in relation to the framework

Stakeholder dialogues

According to Crane & Livesey (2003), stakeholder communication is *"clearly complex and multi-faceted"*. Many aspects should be considered: the direction of flow of the communication, the customisation-level of the communication, and the intention and motivation of the participants.

Three stakeholder dialogues were held in the study period preceding the start the thesis project, with the topics of Health and Food, Mobility, and Energy, Resources and Materials. The focus of the debates was around Klimat 2030, the climate vision of the Västra Götaland region. The dialogues aimed to explore drivers and barriers related to sustainability transitions. A fishbowl format was employed, as it was thought this would increase engagement and lead to a flowing dialogue that is inclusive and productive.

February 2019 stakeholders

In Phase I of the project, seven dialogues were conducted, with the following stakeholder present:

Food: RISE, University of Gothenburg
Mobility of people: Chalmers, Göteborgsregionen, MobilityxLab
Mobility of goods: Volvo Trucks, Urban Water Truck, Chalmers
Energy: Innovatum, Göteborgsregionen, Chalmers

Circularity: Lidköpings kommun, Stena Metall, Chalmers, Göteborgs Stad
Equality: Stadslandet, Göteborgs Stad, Chalmers
Klimat 2030: Chalmers Innovation Office, Johanneberg Science Park, Science Park Borås

The information collected during the stakeholder dialogue sessions was used to map the current situation. This was done by identifying processes (projects), relevant actors, and gaps between the desired future, and the current situation.

Step 3 - Envisage a future situation that can bridge the gap

Leverage point identification

A leverage point can be defined as an area in a system where a small change change can lead to a large overall impact. A leverage point can be frame from three perspectives:

What: What is the gap that needs to be resolved?
Where: What is the local context/problem?
Who: Which actors are involved and interested in this area? What are the related projects?

The stakeholder dialogues were used as a method to identify a number of leverage points. These were developed and shared within the group. Students indicated their interest in leverage points (based on personal interests and personal/educational backgrounds) which was used as a basis for pair formation. The identified leverage points were then further iterated upon by the pairs, based on feedback during presentations and meetings with from fellow students and Challenge Lab staff. Once suitable leverage points had been formed, potential supervisors were identified by Challenge Lab staff and assigned to each topic pair.

9.5 Phase 1 Results

The group arrived at the following principles:

Social

- Embracing the interdependent nature of our human society, every individual has the sense of responsibility and involvement.
- The foundation of our society is sufficiency
- All our interactions are meaningful and honour the humanity in all of us.
- Equal rights and opportunities, the freedom to direct our own lives
- Fair distribution of resources and knowledge, with a culture of sharing and generosity

Economic

- Resource management that allows all humans to fulfill their needs.
- Long lifetime in man-made capital (durable, resource efficient, circular)

Ecological

1. No systematic accumulation of emissions and waste in nature from society (and if needed, restore).
2. Use only the amount of resources that are renewable, not depleting resources.
3. Support and preserve biodiversity.

For the well-being component, the following factors were formulated:

Well-being

Leisure	Institutions (social structures)
Freedom	Intellectual
Purpose	Nature
Safety	Spiritual
Self-actualisation	Social
Love & Belonging	

Initial input from the dialogues suggested Västra Götalandregionen's sustainability strategy was largely being directed by the Klimat 2030 agenda. However, Klimat 2030 does not explicitly mention energy in its ambitions - with its focus areas being sustainable transport, renewable and resource-efficient goods and services, climate-smart and healthy food, and climate-smart buildings. All these focus areas have an energy aspect underlying them, but it arose that due to the lack of specific focus on energy, it was seen as being neglected.

Upon further discussion, the main areas of competence in the region related to renewable energy were found to be wind, biogas and solar. Västra Götaland's wind capacity has already experienced significant growth, being the region in Sweden with the greatest installed wind capacity. Stakeholder engagement also suggested that biogas is somewhat developed, especially in the heavy vehicles sector of transport. Solar was characterised as being fragmented, with a large number of small, disconnected actors. As such, solar appeared to be a potential leverage point in the energy sector. Thus, the preliminary research question was defined as:

“How can the Västra Götaland region support the uptake of solar photovoltaics in the region?

- Who are the key actors in the solar photovoltaics system?
- What are the requirements for an effective intervention by the region?
- How can collaboration and coordination of solar PV actors be facilitated?

However, this process has an iterative character, meaning that depending on the future discussions that will be conducted or other types of research, aspects of the topic can change or focus in an even more limited area of interest. Disregarding that for now, solar PV could be used as a case study, thus laying the foundation for renewable energy transition strategies in the region. This work could support the regional energy directive’s work in driving these transitions.