THE NORWEGIAN SOLAR ENERGY INNOVATION SYSTEM

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NTRANS Norwegian Centre for Energy Transition Strategies

SUSOLTECH The Norwegian Research Centre for Sustainable Solar Cell Technology

UiO : TIK – Centre for Technology, Innovation and Culture University of Oslo

SINTEF

Foreword

Solar energy is expected to be a key driver of renewable energy growth in the energy transition. In this report we look at the Norwegian conditions to engage in solar energy both nationally and internationally. The Norwegian solar energy industry is growing and highly varied. This report takes a broad view on these diverse activities, with the aim to identify strengths and weaknesses in the innovation system that underpins dynamics and further development of the industry.

The report has been written based on results from the research project Conditions for growth in renewable energy industries (RENEWGROWTH) and our activity in the Norwegian Research Centre for Sustainable Solar Cell Technology (SUSOLTECH). RENEWGROWTH is supported by the Research Council of Norway and hosted by TIK: Centre for Technology, Innovation and Culture, in collaboration with SINTEF Digital and Utrecht University. SUSOLTECH joins universities, research institutes and industry, and is funded by industry and the Research Council of Norway.

The report is based on interview and survey data. We would like to thank the participants that devoted precious time and provided valuable insights. We also appreciate feedback and comments from Erik Marstein and Heine Nygard Riise (IFE and SUSOLTECH). Any errors and omission are however the sole responsibility of the authors.

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Executive summary

Large cost reductions have led solar energy to become the cheapest source of electricity in many countries, with large expectations for future growth (IEA, 2020; IRENA, 2021). What does this mean for Norway? In this report, we explore the conditions for Norway to engage in the production and use of solar (photovoltaic) PV technology, both nationally and globally. Based on in depth interviews and survey data we execute an innovation system analysis to identify strengths and weaknesses of the Norwegian PV industry. The Norwegian solar energy industry is highly varied with both national and international activities across the PV value chain. Based on interview and survey results we group the firms in three groups; downstream national, downstream international and upstream.

Downstream national (deployment, integration and use of PV in the Norwegian market)**:** The Norwegian market for PV has grown in recent years and we show that an increasing number of firms have entered the industry. However, annual and cumulative installations in Norway are much lower than neighbouring countries with similar solar resources. There is a large untapped potential in the use of PV in Norway, for instance in the built environment. While there are expectations for growth in installations, we observe that regulatory barriers and inconsistent policies provide barriers to realize such potentials. Firms operating in the Norwegian market also report the lowest satisfaction with existing policies among our three groups. When Norwegian policy related issues are mentioned in relation to motivations, this mainly concerns the lack of (persistent) public sector incentives. Downstream national firms to a lesser degree than the other groups report PV providing good financial opportunities as a motivation for entry. Addressing regulatory barriers and providing stronger policy incentives for use of PV in Norway, could strengthen motivations amongst users and suppliers, and overall strengthen market formation. This would be important if the ambition is to realize the expected contributions from PV in relation to Norway`s electrification ambitions. A further barrier lies in lacking awareness and knowledge of the potential of PV in the Norwegian context. We also see that PV receives less attention in media and government than other renewable energy sources. Raising awareness and strengthening PV as part of education with regards to the applicability of PV in the Norwegian context could strengthen legitimacy. Finally, the carbon footprint of PV modules was raised as an issue. Companies promote low carbon footprint modules, but it is difficult because the majority of the customers do not ask for it, there are no incentives for low carbon footprint modules and their availability is experienced to be low.

Downstream international (deployment, integration and use of PV in international markets)**:** Norwegian firms are active in projecting, installation, operation and maintenance and ownership of both large utility-scale centralized installations, as well as smaller decentralised solutions in international markets. Firms point to the importance of understanding the local conditions of markets and factors which influence them, such as countries` political and regulatory contexts, land rights and demand articulation. A key strength is firms` capabilities to access international markets by establishing a long-term presence on the ground, amongst others by building on previous knowledge and networks in these markets, in order to establish trustful relations to potential customers. Such networks can be built upon previous business relations in other sectors, via embassies or through aid organizations. A further key strength is firms` capabilities in handling risks and securing financial resources. This is particularly salient in low-income markets, where firms experiment with financing models to adapt to user needs. A key motivation for firms as well as public organisations to engage in PV in low-income economies is the falling costs of PV as well as development in adjacent technologies such as digital payments, storage, LED lighting and energy efficiency. This further strengthens the opportunities to use PV to address energy poverty issues alongside climate change mitigation. While the fall in PV prices has increased viability also in competition with fossil energy sources, high capital costs are seen as a significant barrier to more rapid diffusion, particularly given the large risks being priced into credits making capital more expensive. While operational expenses are lower for PV compared to fossil solutions, initial capital expenditures still can be a challenge. Particularly firms active in low-income countries point to high capital costs as a challenge, and the need for strengthening guarantee mechanisms both in terms of volume and applicability for differing solutions, as a way of bringing down costs to ensure further growth and mobilize more private capital. We do however observe a bias, which influences the direction of search towards large scale installations. As such, large scale PV solutions seem to have aligned better with established aid institutions. Actors working with decentralized solutions experience it more challenging to tap into the Norwegian aid mechanisms. Despite this, actors across the board seem to agree on the need for both small and large installations in low-income economies.

Upstream (materials, components or equipment for manufacturing of PV modules)**:** While few firms remain outside of China, Norway still harbours firms that compete and supply materials and products to the international PV industry, such as silicon raw-material as well as silicon ingots and wafers. Upstream segments have been challenged by international market dynamics, and China`s dominance. This is manifested in fierce competition, few remaining customers outside China, and a large degree of firm entry and exit, which in turn affects the conditions for building necessary and important trustful buyer-supplier relations. A key strength in this segment is firms` capabilities to target cost reductions and efficiency improvements in manufacturing of high-quality products, combined with environmentally friendly and low-emitting production. This is tied to strong and continuous knowledge development on the one hand, and conditions for low-emitting energy intensive production based on renewable energy on the other. Firms see the ability to base production on cheap renewable energy as an advantage in markets which reward low carbon footprints. However, upscaling of production capacities is seen as critical in upstream segments in order to remain competitive. Since upscaling is a general trend among customers, Norwegian firms see the need to scale in order to maintain important customer-supplier relationships which are key to continuous learning and improvements in production. However, realizing the upscaling potentials is challenged by mobilisation of financial resources, which is seen as a key barrier. A lacking industrial strategy is also pointed out by upstream firms. Recent initiatives to rebuild a stronger European PV manufacturing industry that highlights sustainability criteria, would favour Norwegian suppliers if implemented. A stronger involvement of Norwegian authorities in attempting to shape regulations and markets to favour products with low carbon footprints, could further leverage the natural competitive advantage of Norwegian firms.

Observations across value chain segments: Knowledge creation and utilisation of knowledge for experimenting with new or improved solutions is generally strongly performing across the segments. Collaborations between customers and suppliers are vital across segments, and intermediary organisations (such as Solklyngen, Solenergiforeningen and FME SUSOLTECH) are important arenas for knowledge exchange. Important knowledge creation is connected to digitalisation and automation, where also further strengthening of capabilities is mentioned. This goes for optimizing production processes in upstream production as well as monitoring and integrating production with storage technologies and demand side management solutions in downstream segments. Additionally, firms express the need to align the duration of public support for technology development with the product development cycle, and not, for instance, to stop when a new technology has been demonstrated. While general satisfaction with public support for knowledge and technology development is expressed, some actors point out that experimentation and piloting for more large-scale projects is challenging to secure within the Norwegian system.

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1 Introduction

Large cost reductions have led solar energy to become the cheapest source of electricity in many countries, with large expectations for future growth in installations worldwide (IEA, 2020; IRENA, 2021). What does this mean for Norway? In this report, we explore the conditions for Norway to engage in the production and use of solar photovoltaic (PV) technology, both nationally and globally. To analyze the Norwegian conditions, we perform an innovation system analysis of the Norwegian PV industry to identify strengths and weaknesses. Previous reports have analyzed the situation for PV (Multiconsult & AsplanViak, 2018) and presented a roadmap that suggests large growth in revenues and employment both nationally and internationally (FME-SUSOLTECH & Solenergiklyngen, 2020). However, to our knowledge there exist few systematic analyses of the strengths and weaknesses in the underlying innovation system for developing the Norwegian PV industry further.

The motivation for our empirical study is twofold. First, PV is a global high growth industry, and is expected to be a key driver of growth in renewable energy globally (IEA, 2020). PV is also highlighted in Norway`s Energi21 strategy (strategy for energy related research and innovation), where the Norwegian industry`s international growth potential is recognized. Several Norwegian firms are active in international PV markets, both in terms of supply of materials and components as well as in projecting, installation and ownership of both large-scale solar parks as well as small-scale decentralized solutions. Materials and components for the solar industry produced in Norway, based on renewable energy, have a significantly lower carbon footprint than those supplied by Chinese firms (Ryningen et al., 2021). Norwegian actors` international solar energy activities and investments, particularly in low-income economies, are also important for accelerating energy transitions (Multiconsult, 2018). Second, PV deployment in Norway is substantially lower than in many other countries. Yet, there is growth in national installations and an increasing number of firms active in the Norwegian market in recent years. In light of expected increases in power demand driven by substantial electrification ambitions in Norwegian industry and transport, PV has also been mentioned as a key source alongside other renewable energy sources. For example, the Norwegian water resources and energy directorate (NVE) has stated that PV contributing with 7TWh to the Norwegian electricity system by 2040 could be realistic (Lie-Brenna, 2021). The roadmap for the Norwegian PV industry suggests 2-4 TWh by 2030, provided 20-30% annual growth rates (FME-SUSOLTECH & Solenergiklyngen, 2020). Solar energy is typically awarded with high social acceptance (Sütterlin & Siegrist, 2017), particularly in rooftop segments (Cousse, 2021). Solar energy is also viewed favourably in the Norwegian population (Kantar, 2020). This motivates a study of which factors that could provide drivers and barriers to more PV deployment also in Norway. As the Norwegian PV industry is highly varied, our study therefore covers both national and international activity across the PV value chain.

We employ the technological innovation system framework to guide our analysis, which enables the identification of system strengths and weakness. This can assist policy makers and other stakeholders in identifying areas where Norway has advantages that can be built upon, or weakness that hamper further development, which in turn could be addressed by policies and/or regulatory change.

The report is structured as follows. In section 2, we present a short description of PV technology and industry. We then present the technological innovation system framework in section 3. Section 4 presents the data and methods used. In section 5, we provide a brief overview of the structure of the Norwegian PV industry. Section 6 presents findings from the innovation system analysis, focusing on the key processes in the innovation system, while section 7 sums up key strengths and weaknesses observed.

2 PV technology and industry

2.1 A snapshot of global development of PV

Sola PV initially emerged as a niche technology but has developed dramatically over the past decades in terms of efficiency and price. Between 2010 and 2019 prices for PV were reduced more than for other renewable energy technologies, declining by 82%, (IRENA, 2020). The decline can, amongst others, be attributed to the improvement and knowledge development in material efficiency, production optimization, economies of scale, and not the least strong demand pull policies (Nemet, 2019). Today PV is the cheapest energy source in many countries. In 2020 almost 135 GW were installed globally, of which a large share was in the utility scale segment (IEA, 2021). The IEA PVPS estimates the global cumulative PV capacity to 760 GW in 2020 (IEA-PVPS, 2021). Large expectations for growth in global installations are projected, even by the International Energy Agency (which until recently underestimated PV growth rates) (IEA, 2020).

The PV industry emerged in a highly globalized pattern with a significant shift of activity towards emerging economies, and in particular China. By 2016, more than 70% of crystalline PV panel manufacturing was concentrated in China and Taiwan, and both upstream and downstream parts of the value chain increasingly shifted towards Asia (Binz et al., 2017; Quitzow et al., 2014).

Overall, the life-cycle of the global solar PV industry could be divided into three phases: a fluid phase (1965 – 1990) where most industry's activities were experimental and exploratory, a transitional phase (1990 – 2005) where first mass-markets for the technology emerged with new entrants all over the world, and a standardized phase (2005 – today) where PV modules turned into a globally standardized commodity for uniform global mass markets (Binz et al., 2017).

2.2 A snapshot of the development of the Norwegian PV industry

Norway built up a remarkable PV industry over the last decades, with central global industrial players (Klitkou & Coenen, 2013). The Norwegian PV industry has evolved since the mid-1990s when the first PV manufacturing firm, Scanwafer, emerged (Hanson, 2017; Klitkou & Godoe, 2013). The PV industry emerged initially with a focus on upstream manufacturing towards international markets. In the formative phase, the industry drew on the strong material competences built up over many decades in the processing industry with tight connections to research institutes and universities, in particular related to silicon. The PV industry thus had strong knowledge foundations to build upon, in addition to access to cheap electricity, cooling water, and infrastructure (Hanson, 2017). During the first decade of the 2000s, the large global player Renewable Energy Corporation (REC) and a number of suppliers grew forth. Following China's entry to the PV industry, the dramatic increases in production capacity and rapid decreases in price challenged many of the established firms in the industry. Alongside the large price declines, firms linked to PV deployment emerged targeting both the international as well as the Norwegian markets (Normann & Hanson, 2015).

The continued growth in global PV markets remains an opportunity for Norwegian actors. In Norway, a report shows that Norwegian or Norwegian-owned companies in 2020 owned a production of 19.4 TWh of renewable energy outside Norway's borders. 1,7 TWh was estimated to come from PV. In the autumn of 2020, Scatec bought most of SN Power, adding their respective production last year. Statkraft also signals growing involvement in PV, spearheaded by their acquisition of Solar Century which adds a 6GW PV pipeline (Hirth, 2021).

The market for PV in Norway is, and has been, small compared to that of other countries. Figure 1 compares annual solar energy deployment in Norway to that in Sweden and Denmark, which have similar solar irradiation levels (i.e. similar amounts of sunshine). As illustrated, Norway`s annual installations are the lowest among the three countries. The growth in annual installations has, however, increased in Norway, albeit with a decline from 50MW in 2019 to 40MW in 2020. The total cumulative installations have been estimated to 160MW in Norway (NVE, 2021). Total cumulative installations in Norway are thus lower than annual installations in Sweden in 2019.

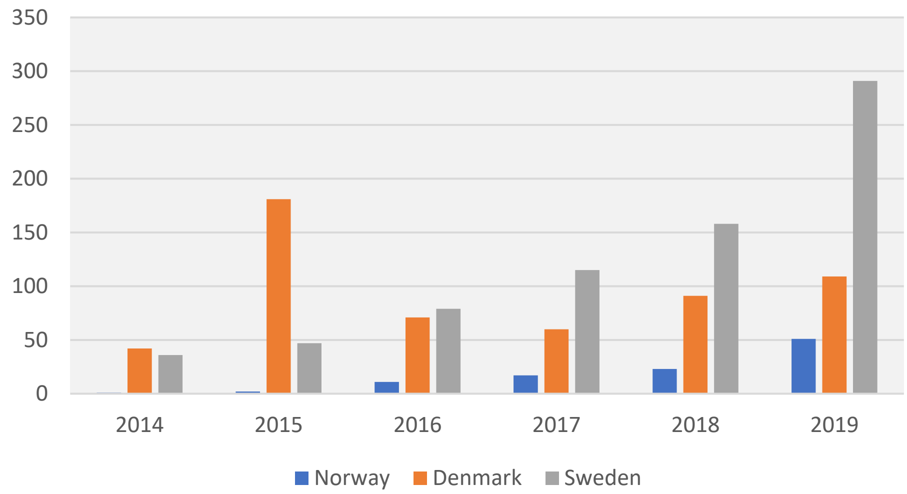

Figure 1: Annual PV capacity additions in Norway, Denmark and Sweden 2014-2019, MW per year ("IEA PVPS National survey reports 2014-2019,")

The technical potential for PV in Norway is, however, large, with estimates ranging between 30GWp and 50GWp on buildings (FME-SUSOLTECH & Solenergiklyngen, 2020). Previous research has shown that solar energy has potential in Norway, but has also pointed to a number of barriers to the realization of the technical potential (Xue et al., 2021). A recent study showed that the high up-front investment of photovoltaics and limited information and awareness of the possible benefits are the main barriers for users (Xue et al., 2021).

An emerging phenomenon in which many actor groups are involved in is solar prosuming (Inderberg et al., 2020). In Norway, PV does not form a significant part of the government's vision of the country's future electricity mix (Winther et al., 2018). Consequently, prosumers, who produce electricity and feed it to the grid, are not actively encouraged in the PV market. A study of prosumers in Norway examined people's rationales for investing in solar power and how they use this technology to signal identity (Winther et al., 2018). The results indicate three groups of prosumers in Norway: individual prosumers (who have taken the initiative to install solar PV), 'smart house' dwellers and ecovillager. While all three share an emphasis on self-consumption in terms of maximising electricity use in periods with sunshine but they also make use of solar technology to signal identity (conversion) (Winther et al., 2018).

Similarly, a study on exploration of positions, perceptions and interconnections that influence prosuming activities among national policymakers, relevant stakeholders such as grid companies, and the prosumers, revealed that prosumers` pursuit of particular identities to be of importance, rather than financial reasons (Inderberg et al., 2020). The results also indicate that widespread prosuming requires economic considerations. Given the current policy framework in Norway, the authors conclude that if increasing prosuming activities becomes a desired political goal, this will require stronger financial incentives for individual prosumers, and a deeper understanding of the interplay among actors across arenas and sectors. Third-party market actors such as the solar and building industry play important roles to facilitate prosuming activities (Inderberg et al., 2020).

3 Technological innovation system framework

We employ the technological innovation system (TIS) framework in this study. A key insight from the field of innovation studies, is that innovation rarely occurs in isolation, but rather is a collective activity, which occurs in a broader system (Bergek et al., 2008; Hekkert et al., 2007). The key idea behind innovation systems is that novel technologies and industries emerge on the basis of interaction and interdependencies between actors. These interactions enable the flow of knowledge and technology between actors in the system, which in turn can facilitate the development of successful technologies. The core idea is that new technologies and industries evolve over time and can become successful if a strong innovation system is built up.

In many cases, such a system can have certain strengths, but typically also have a set of different weaknesses, which hampers the system, and ultimately the technology and industry from developing. It is therefore important to identify such system strengths and weaknesses in order to identify processes and activities that can be leveraged and built upon, and those which need strengthening (Hellsmark et al., 2016).

To analyze an innovation system, it is important to have an overview the structure of the system. The structure is comprised by different building blocks, which include actors such as firms, universities, public sector agencies, the networks and relations between these actors, as well as the different rules that guide the interaction between these, such as policies and regulations. The key novelty of the TIS approach compared to previous innovation system approaches is the focus on system dynamics, referred to as functions or key processes discussed in the following section.

3.1 Key processes in innovation systems

The central premise of TIS analyses is to analyze how the system functions in order to support the development of a technology and industry. In order to do that a set of key processes have been identified and used to evaluate how the system functions. These are elaborated upon in table 1.

Process	Characteristic
Entrepreneurial experimentation	Entrepreneurial experimentation by start-ups as well as established firms is linked to problem solving through trial-and-error with different products, processes, services, applications and business strategies. Although experimentation is associated with uncertainty it is important that many actors experiment to contribute to overall improvement of the system and ultimately the technology (Jacobsson & Bergek, 2011). Experimentation is related to high risk and uncertainty both in economic and technological terms (Bergek et al., 2010). Economically, experimentation is usually linked to large costs, and the success of individual experiments is not given. In part this is linked to technological uncertainties, since there tend to exist competing designs and technical solutions, and which ones that are winning and losing may change over time.
Knowledge development	This process is understood to lie at the core of a TIS as the evolving knowledge base determines emergence and growth of the system (Bergek et al., 2008). Knowledge, learning and new combinations of existing sets of knowledge forms a central dimension for system dynamics. Knowledge development can happen through research & development, testing and demonstration activities and through continuous learning connected to ongoing production and use. Firms tend to collaborate with other actors to develop knowledge, since individual actors rarely possess all relevant knowledge sources, particularly in emerging and rapidly developing technological fields.
Influence on the direction of search	In order for a TIS to develop a range of organisations and actors need to join (Bergek et al., 2008). Influence on the direction of search is related to how firms or other organisations are influenced to discover opportunities within the TIS or are provided with incentives that make them willing to invest. A positive expectation about the development of the technology is a key aspect here. This expectation may be based on changes in customer attitudes, prices, regulations, policies and market development.
Market formation	The process of market formation is key to technology diffusion, articulation of demand and inclusion of users, and hence to TIS growth as it opens arenas for exchange of products and services (Jacobsson & Bergek, 2011). This is critical for the development of new technologies, since it establishes relations between users and suppliers, which is highly important for development and improvements of technologies. Hekkert et al. (2007) distinguish between niche markets and policy induced markets, where niches constitute specific applications and advantages, whilst policy driven markets usually include some sort of subsidy (for instance tax regimes, feed-in tariffs, or procurement initiatives). Subsequent to the formation of niches, markets may evolve to become bridging and mass markets, with changing and increased competition and market dynamics.
Legitimation	Legitimation is the process of gaining legitimacy in the eyes of stakeholders. New technologies tend to be associated with the "liability of newness" and compete with more mature technologies (Bergek et al., 2008). The legitimation process is about alignment with rules, regulations, standards, policies and societal norms more broadly. The legitimation process concerns how PV in general, or the specific product or service that firms deliver, is rewarded with social acceptance and viewed as desirable and appropriate (or not) among stakholders. These can include; users, producers, investors, civil society and policy-makers in order to generate demand and support. Furthermore, legitimation is about how a technology matches with existing policies, institutions, regulations and standards. Actors may deliberately try to influence this alignment by working to influence policy makers or general publics attempting to shape the desirability of a technology.
Resource mobilization	Mobilisation of different types of resources for the development, diffusion and utilization of new technologies, products and processes. This includes capital, competence and human resources and infrastructures.

Table 1: Key processes in the formation of a technological innovation system

4 Data and methods

This report is based on two main data sources; semi-structured interviews and a survey of firms.

4.1 Interviews

The interview material is comprised of 23 interviews with actors engaged in the Norwegian PV industry. We sought to execute a balanced set of interviews with a variety of actors in terms of value chain position, size and geographical orientation, as discussed in section 5.

We developed an interview guide intended to capture the main elements of the TIS framework, and particularly the system functions. The duration of interviews was typically 60 minutes. The interviews were recorded (with consent from the informant) and subsequently transcribed. The interviews were executed in the period 2018-2021. Information about the purpose and scope of the interview was relayed to the informant in advance.

The transcribed interview data was coded in relation to the TIS framework. Text pieces from the interviews were coded in relation to which system function it connects to. As a second step we extracted all codes allocated to a certain system function and systematically assessed the material. Based on the assessment of the coded material we wrote up presentations of the individual TIS functions.

4.2 Survey

The survey was targeted to Norwegian firms engaged in the solar industry. The sample for the survey was put together from membership lists in industry associations, industry reports, and desk research. The criteria for inclusion in the sample was that the firm was Norwegian and that we had reason to believe the firm had delivered, or had ambitions to deliver, products or services to the solar industry. The original sample consisted of 141 firms. The survey was web-based and conducted in May-June 2018. 73 firms responded to the survey. After having removed incomplete responses and responses from firms with no reported ambitions in the solar industry, we were left with a total of 62 firms in the data set, which represents 44 per cent of the total sample (minus the firms that were not in the solar industry).

4.2.1 Other data sources

While the report is primarily comprised of primary data collected and analyzed by the authors, we in some instances rely on additional data sources, such as such as reports, news articles and available data bases (retriever.no for news article analysis and stortinget.no for mentions in parliament).

5 Structure of the Norwegian PV industry

The Norwegian PV industry is varied, with firms present in many different value chain segments, and different markets globally. Given this variation, we chose to group the firms. We used the type of activity, in terms of main value chain segment, and the geographic orientation, in terms of main markets, as key dimensions for grouping. The grouping of firms was based on information from survey responses, interviews as well as desktop research.

When it comes to the type of activity, there are various ways in which the PV value chain can be depicted. Figure 2 illustrates one typically used portrayal, with a main distinction between up- and downstream activities. Since there are a limited number of firms in the Norwegian PV industry, we opted to use the overall categories of up- and downstream to distinguish the type of activity.

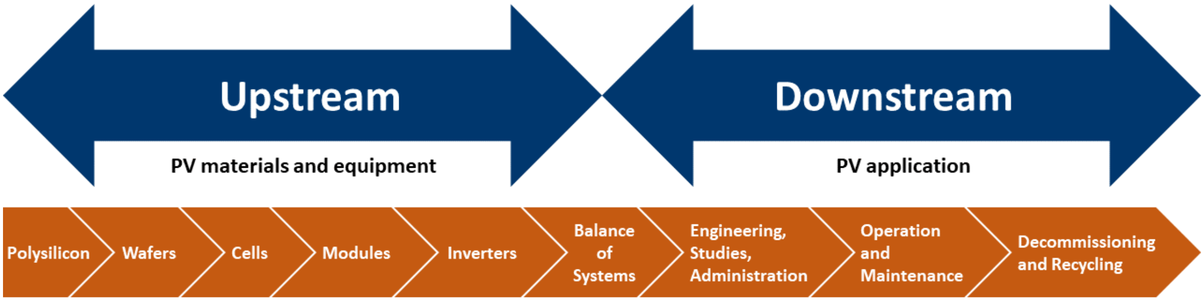

Figure 2: PV value chain. (Based on a figure from the source: Solar Power Europe)

The upstream segments include the manufacturing of raw-material (purified silicon), the production of silicon ingots (blocks), the slicing of thin silicon wafers as well as manufacturing of cell, module and balance of system components and inverters. In our operationalization, the upstream segment thus includes activities linked to the manufacturing of materials, components to fabricate the PV module and associated components such as inverters. Norway has a limited set of actors engaged in upstream segments (see Figure 3), but we opt to distinguish these from downstream actors, since firms in these two overall segments deliver to quite different types of customers and markets, which have quite different market and technology characteristics (Hipp & Binz, 2020).

The downstream segment includes activities linked to the use of PV modules to generate electricity, such as projecting, installation, financing, ownership and operations and maintenance. This segment is more closely connected to the end users and connects to the electricity sector, and depend on the local market conditions that firms are active in. Therefore, we use the main market orientation of firms (national vs international) as a further categorization of firms.

Based on the survey responses as well as information provided in interviews to questions about firms` main activity and main market, the distribution of firms in our study across the value chain and market orientation is shown in Figure 3.

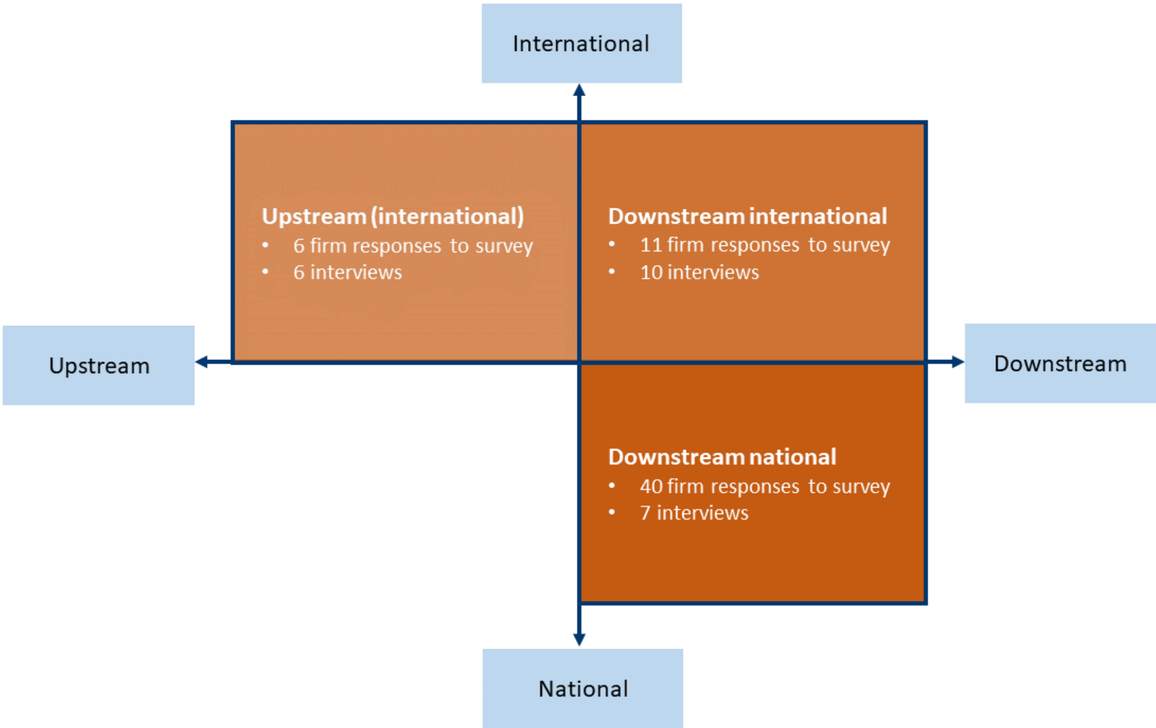

Figure 3: Grouping of firms based on main value chain segment and market of firms in our study (Source: survey and interviews).

Firms in the upstream segment are oriented towards exports to international markets, since there is no full PV module value chain in Norway and countries like China have large manufacturing capacities. In the downstream segment, firms are more mixed in whether their main market is in Norway or abroad. For this reason, we distinguish between downstream firms that have a main orientation towards the Norwegian market, and those with a main orientation towards international markets. Although there is variation, we group the firms in the following 3 main groups, given share commonalities in market orientation, and with respect to how they connect to the key processes in the innovation system:

- Downstream national: Actors engaged in the deployment, integration and use of PV modules in the Norwegian market.
- Downstream international: Actors engaged in the deployment, integration and use of PV modules in international markets.
- Upstream: Actors engaged in the PV module value chain, supplying materials, components or equipment for manufacturing of PV modules.

Finally, it is worth noting that the Norwegian PV industry is dominated by small firms. Figure 4 displays how firms are distributed in terms of numbers of employees and shows that most firms have less than 10 employees.

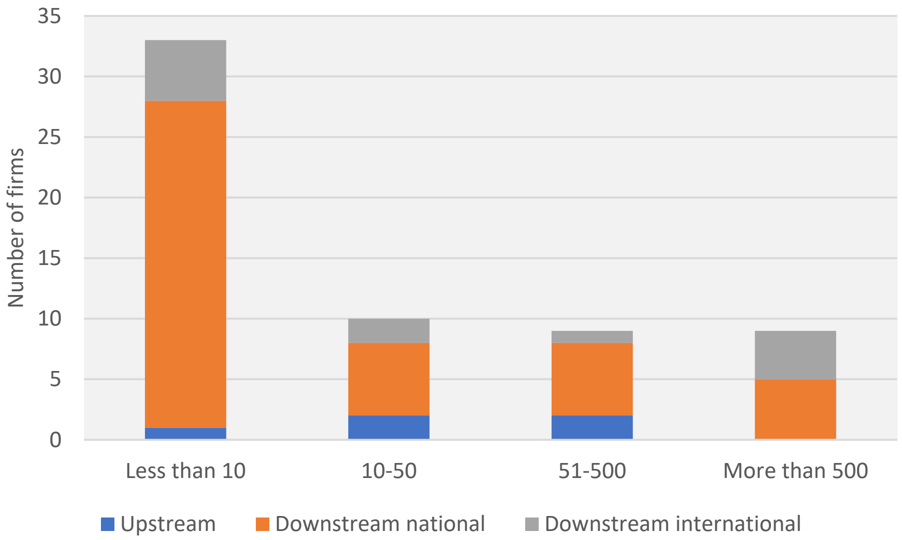

Figure 4: Number of employees in 2017 (Source: survey)

With respect to firm size, it is also worth noting that some of the firms reporting larger numbers of employees are firms with main activities in other markets than PV. Figure 5 shows that the majority of firms report to have PV as their main industry, but several firms also have their main activity in other markets, such as in broader energy related activities and in buildings and construction.

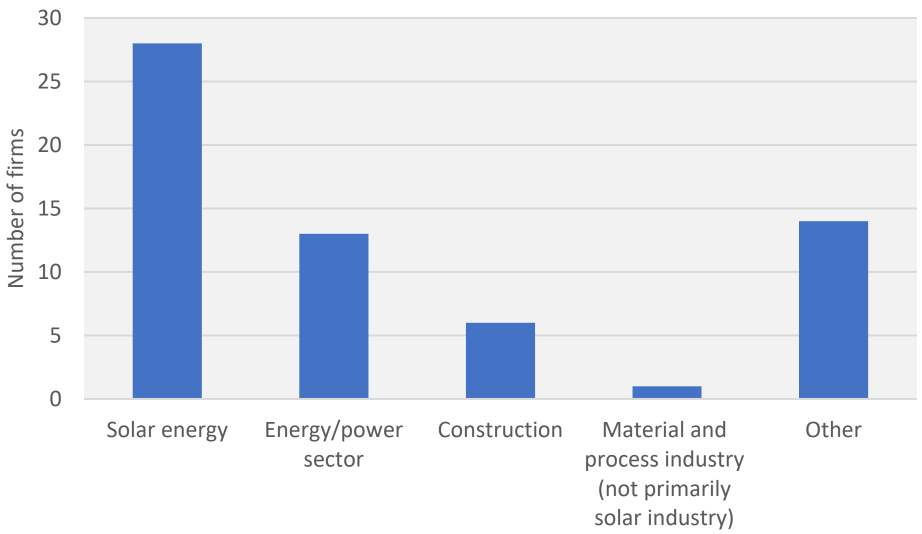

Figure 5: Core industry of firms active in PV (Source: survey)

6 Key processes in the Norwegian innovation system for PV

6.1 Entrepreneurial experimentation

Entrepreneurial experimentation with, and within, PV is happening across the value chain, from materials to system integration. This goes both for new entrants as well as firms that have been established in the industry over time. In fact, in most interviews, actors point to efforts to introduce, use or combine, new products, technologies, processes, or business models. Overall, this suggests a high degree of experimentation and variety creation, which is important for an innovation system to evolve. Overall actors point to experimentation as necessary given the risks linked to rapid changes in the industry, technology and market conditions. This can be for instance connected to the changes in dominant solar cell design, such as the shift from multi- to monocrystalline silicon, and the rapid decline in prices discussed in section 2. Furthermore, PV is described as a "simple", modular technology with rather low entry barriers, which can make the competitive environment somewhat unpredictable.

The degree of experimentation in the Norwegian PV industry is reflected in Figure 6, which shows the annual number of firms entering the PV industry (by first sale related to PV) across our 3 segments. It shows that the number of actors that enter the industry has increased over time. We observe the largest share of new entrants linked to the downstream national segment from 2014.

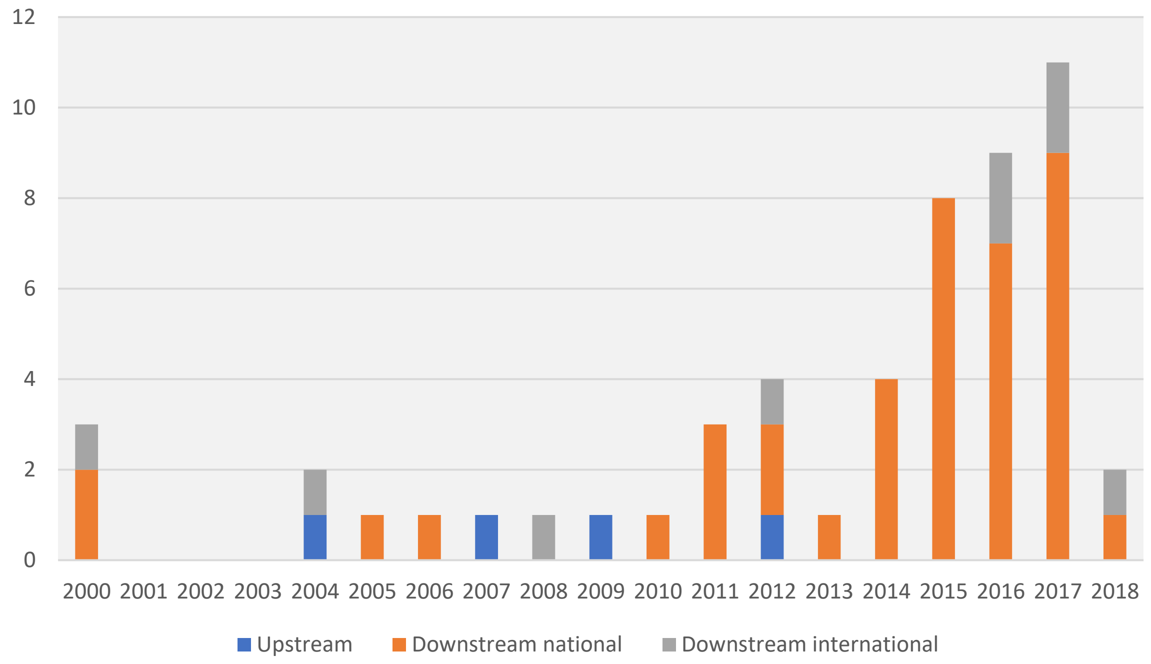

Figure 6: Entry of Norwegian firms to the PV industry, based on the response to survey question about which year firms had their first sale related to PV (Source: survey).

Figures 7-10 display firms` assessments of different types of risk factors connected to changes in policies and regulations, demand, price competition and access to financing. We note that all firms in the upstream segment report a high or very high risk linked to aggressive price competition. Over half of the actors in the downstream segment both nationally and internationally do however also report high or very high risks connected to this.

Over half of the internationally oriented firms, both in upstream and downstream, report a very high or high risk connected to changes in policies, taxes or duties, whereas nationally oriented firms report somewhat lower risks. At the same time, the majority of firms across the segments report a moderate to low risk connected to variation in demand. This could be interpreted as firms expecting overall stability in demand, while the responses linked to subsidies and policies could represent some of the particular uncertainties connected to changes in public policies in the countries in which Norwegian firms operate in, or export to. Finally, risks connected to weak access to financing are somewhat more reported by firms with international orientation than those with a national orientation.

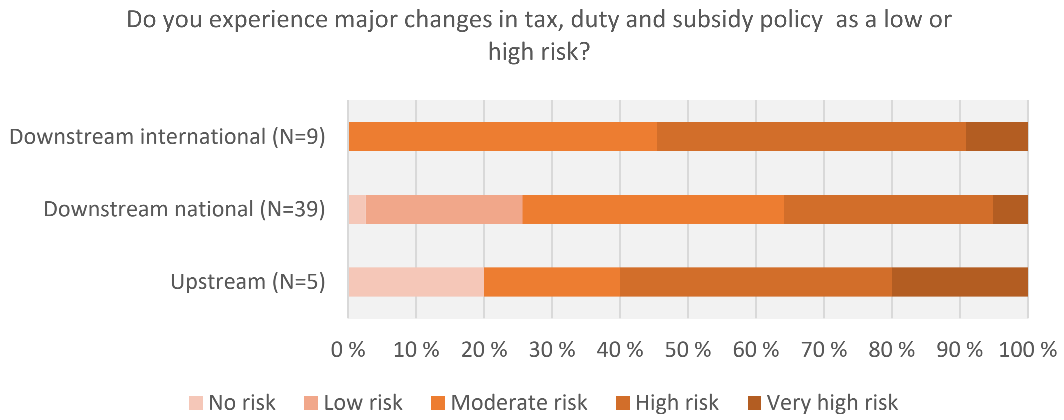

Figure 7: risks linked to changes in tax, duty and subsidy policies (Source: survey)

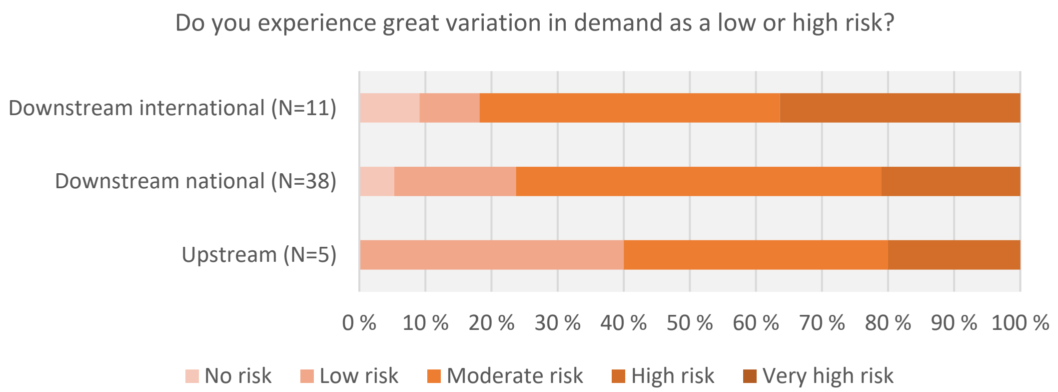

Figure 8: Risks linked to variation in demand (Source: survey)

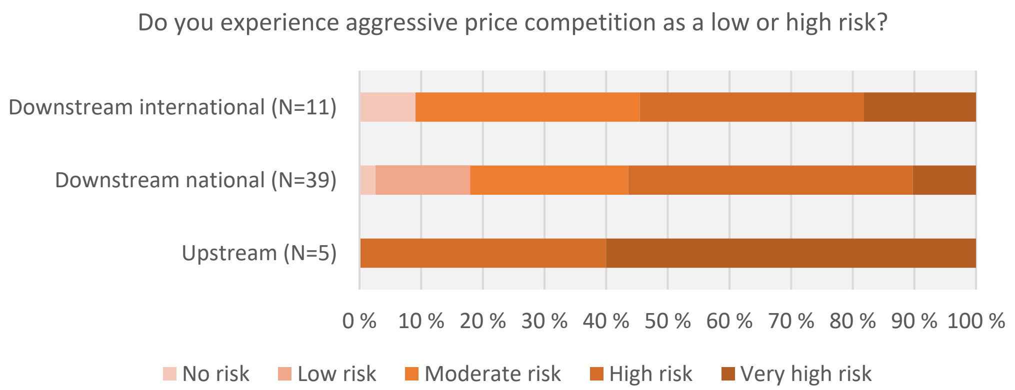

Figure 9: Risks linked to price competition (Source: survey)

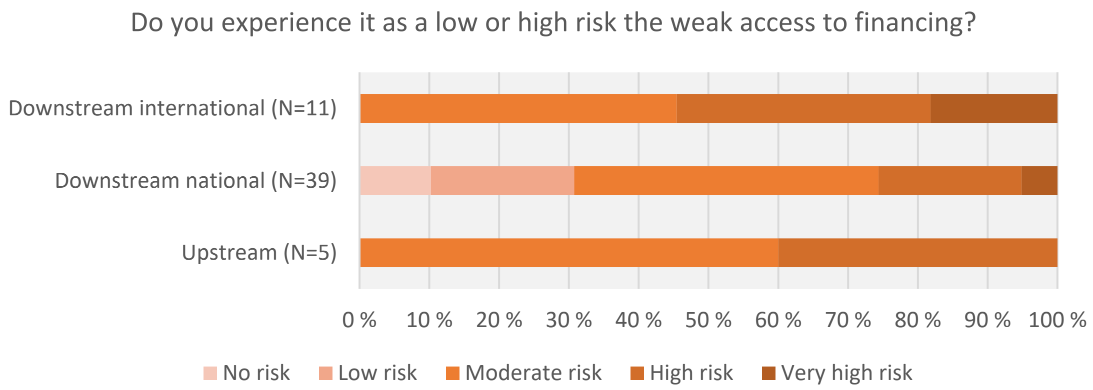

Figure 10: Risks linked to weak access to financing (Source: survey)

6.1.1 Downstream - National

In the downstream segment oriented towards the national market, entrepreneurial experimentation could refer to the introduction of a new technology that monitors existing PV systems. One example refers to the employment of a digitalization platform. This is a quite progressive approach to connect various and diverse interfaces that support PV systems. Such a platform connects diverse interfaces for communication to monitor and offer flexibility to the end user in controlling energy saving. Visualization in the app is important for customers to have a simulation of how much energy the PV system should produce. Conservative and realistic calculations of the production and consumption, through the app, of the PV systems are seen to provide happy customers in the long-term.

Entrepreneurial experimentation could also refer to the combination of PV technology with other technologies. The example here describes the ‘competition’ between a green roof with plants, happy bees and bumblebees, and a blue roof that slows down the water coming from heavy rain so it doesn't overload the drainage system. These can be combined with solar PV systems as well.

While firms in this segment experiment with various solutions for system integration, it is more rare for companies to develop new products, but some companies also pursue this. One example is the development a snow melting system for solar installations. There are also ideas and plans regarding energy storage solutions to buffer the grid and to serve as a way of maximizing the potential of solar energy, in terms of avoiding to export excess solar energy to the grid but rather store it and use it for other applications. This could lead to a high degree of self-consumption.

6.1.2 Downstream – International

This group of actors is varied as firms experiment with PV at different scales, ranging from large centralized to small decentralized solutions. Norwegian firms are involved in project development, operation and maintenance and/or ownership of large utility scale PV plants, as well as sales and installation of decentralized solar home systems or “pico” solutions, such as solar lamps or PV powered devices used in agriculture.

Due to the “simplicity” and low entry barriers in PV, competitors can be smaller startups, which are perceived to move with high agility in markets. Collaborations, joint ventures, or mergers and acquisitions with such firms, can be strategies for experimentation and market entry for larger firms. In some instances, this was reported as an entry mode to PV for larger firms. As such, entrepreneurial experimentation is tightly connected to international market access, and the ways in which actors connect to the customers and markets in a large variety of countries and regions.

Hands-on approaches to the market actors target is important, and typically requires a long-term presence “on the ground” in order to build trustful relations to customers.

A sub-group in this segment is solely focused on markets in low-income economies, with varying, and at times unstable, institutional and regulatory framework conditions as well as energy systems. It’s worth mentioning that entrepreneurial experimentation in this context is about replacing fossil solutions such as coal or diesel fired plants. Overall, uncertainty and risks in such contexts are strongly connected to mobilization of financial resources, particularly given the large risks being priced into credits offered by commercial banks and actors, making capital more expensive. This is also reflected in Figure 10, where the majority of firms in this segment report a high or very high risk connected to weak access to financing. Entrepreneurial experimentation in these segments is about building capabilities to handle such risks, and secure financial resource mobilization to bring down the costs of projects.

Indeed, in the low-income economy context, entrepreneurial activities are about experimenting with and implementing solutions and business models that suit user needs, which particularly relate to price and cost requirements. Overall, in the context of low-income economies, uncertainties and risks are being mentioned frequently in interviews, and experimentation with business and financing models to reduce these are important. While energy needs certainly are strongly pronounced in low-income countries, given the large number of people still living without energy access, purchasing power to handle upfront costs associated with PV is lacking. For this reason, actors are experimenting with new business and payment models towards private consumers. Amongst others this relates to developing business models where up-front costs can be avoided through leasing models, such as the use of so-called Pay-Go models or Scatec Solar`s Release concept for mid-size installations, based on a leasing approach.

Digitalization is mentioned as a key dimension to entrepreneurial experimentation across all actors in the downstream segment. This relates for instance to different types of monitoring systems and optimization of production, as well as to facilitate interactions with users and payment systems.

6.1.3 Upstream

In the upstream segment, experimentation primarily is about upscaling production and introducing and/or using new processes and equipment to manufacture products, materials and components which go into the PV module chain. Since most of the activity in this segment is geared towards exports, experimentation is key to remain competitive in highly challenging international market conditions and as such strongly influenced by dynamics in the global PV manufacturing industry. These dynamics include rapid price drops, productivity enhancements and improvement of manufacturing processes (connected to automation and digitalization), upscaling of manufacturing capacity and shifts in dominating technological trajectories (from multi- to mono-crystalline Silicon).

The rapid price drops and fierce competition means that manufacturers are constantly shaving manufacturing costs by improving and making processes more efficient. Actors point to new production equipment, which itself has decreased in price, as well as efforts to scale up and automate, digitalize and monitor production processes and equipment as important. Automation and digital solutions are however not off-the-shelf solutions and need to be adapted to current processes and equipment, and for this reason become part-and-parcel of current experimentation. Scaling-up production volumes and making manufacturing more efficient is also about understanding and using knowledge about material properties in manufacturing. For this reason, user-producer interactions (as discussed under knowledge development) are pointed out as highly important, because it enables producers to learn how changes in manufacturing processes affect the results of customers. Several informants point to this continuous alignment between what customers need and what producers can supply as a key way to remain competitive, which relies on trustful collaborations. Scaling of manufacturing capacity is also an important way of growing alongside growth trajectories of customers. Interviewees suggest that refraining from scaling could jeopardize customer relations that have been built over time. However, as discussed under resource mobilization, raising the necessary financial resources to scale is seen as a key challenge.

Finally, circular economy thinking has also entered this segment, for instance in REC Solar`s new process for use of recycled silicon. Experimentation in the upstream segment is also affected by the geographical contexts, and particular the dominance of China. In some cases, fear of copying has provided a barrier and stopped firms from industrializing and scaling up solutions.

6.2 Knowledge development

Overall, actors in the Norwegian PV industry highlight the need for continuous knowledge development given that technology and markets are under constant and rapid development. Actors point to well established Norwegian knowledge fields linked to materials (upstream), execution of large and complex project (downstream international) with learning from other sectors such as offshore or hydropower as key competitive assets in global markets, as well as knowledge from suppliers and customers (downstream national). Given that actors unanimously point to knowledge development as a core individual and collective activity, and that actors in general are satisfied with public support for knowledge creation and sharing, this process is assessed as strongly performing. Many actors both in up- and downstream segments point to engaging in research & development (R&D) projects with differing funding sources, with the Norwegian Research Council and EU as frequently mentioned. As such, this function thus has important ties to resource mobilization, given the importance of publicly funded R&D.

6.2.1 Downstream - National

In this segment the development of knowledge and knowledge transfer to a large extent refers to the market of solar PV. The knowledge transfer between companies and suppliers is considered valuable, where companies tend to work with the same suppliers to avoid the time-consuming learning process of products' technical details and requirements. Knowledge transfer in this example starts when trust between them has been established, and afterwards, product development, feedback on products and future planning could be discussed. There are examples where companies pitched ideas for products to their suppliers who further developed the ideas with their R&D department.

The knowledge transfer between companies and customers is also possible. Sometimes, companies have an educational and consultancy role, depending on their customers' needs, to explain how a solar PV system works, its consumption, requirements, prices, and setting realistic expectations to weigh the installation towards the consumption. Similarly, companies strive to give technical and professional information to their customers about solar PV so that they can make informed decisions where solar energy production estimations could be involved. Estimation programs for solar PV calculate energy production based on an area's temperature and weather data for the last 20 years. However, solar energy estimations and models in use are criticized for being tested in higher temperatures than in Norwegian weather conditions, while the production of the maximum capacity of solar modules has to be tested in Norway for more accurate estimations.

Many strategies to gain new knowledge about PV have been mentioned. For instance, companies gain scientific / general knowledge by following news and updates in the sector, reading relevant magazines, newsletters, as well as the market news, and they try to understand the existing opportunities and needs. Cooperating with experienced competitors, producers and suppliers are also considered strategies for gaining knowledge. Other strategies involve the collaboration in EU projects where companies have a common target, for instance to make an off-grid community. Collaboration with university, research institutes and scientists has been mentioned in the context of project development or knowledge exchange.

Networks, like Solklyngen and Solenergiforeningen, are considered important in terms of knowledge exchange, particularly regarding sharing of experience and competence in the field. There are also good networking opportunities with diverse companies. The most important factor of joining such networks is the power of working together with competent actors and having common goals. This is also a learning process where many project presentations and visions could be valuable for participants.

6.2.2 Downstream - International

Actors in this segment note that important knowledge development is linked to understanding the market conditions in the countries and regions that they target. As such, knowledge development in this setting is about gaining sufficient knowledge to minimize risks associated with foreign market entry. As such, this function connects intimately to human resource mobilization. Firms point to attracting employees or building up internal competencies with specific knowledge about the particular markets that firms seek to enter, or to maintain a presence. In this segment the main areas of knowledge development relate to system integration, project development and in relation to mobilization of financial resources. Several actors mention using digital solutions either for production monitoring or customer integration as key areas for knowledge development. Additionally, demand side management (i.e. understanding, monitoring and controlling energy use patterns) and interactions with other technologies such as storage solutions or energy efficiency measures are seen as areas that need further knowledge development, which actors engage in. Particular applications, such as floating PV, are areas where actors see the necessity of doing more foundational R&D as well as testing and demonstration. Both for floating PV as well as utility scale projects, actors point to important and relevant competencies from the petroleum sector, such as large-scale project execution.

Actors in low-income economies point both to the opportunity to adapt existing solutions, as well as the needs to develop new and market specific knowledge in the particular contexts they intend to operate. Such market specific knowledge is key to secure financing, since credits and loans usually are tied to due diligence checks. Feasibility studies to explore production potentials are important as well. NORAD offers opportunities to support this type of knowledge development. Moreover, firms in this segment also mention engaging in knowledge development activities together with users and actors based in the specific countries they engage in.

6.2.3 Upstream

Knowledge development is assessed as highly important for maintaining competitiveness in a very challenging market for upstream firms. For many firms in this segment, quality is a key competitive asset, and knowledge development is highly important to facilitate continuous improvements. The key sources for learning are interactions with customers and suppliers, and several actors point to the important role of trustful partnerships with other firms or research institutions. Knowledge creation is therefore intimately tied to ongoing production and learning by doing. One of the main learning mechanisms is to see how a product, service or process works for the customer, with a particular emphasis on quality improvements and cost reduction. Actors also point to the necessity and benefits of knowledge creation linked to ongoing production, for instance in terms of optimization of equipment or the implementation of digital or automation solutions. In geographical terms actors point to collaboration with other Norwegian actors, but this depends on the value chain position. Firms that have knowledge collaboration, overall evaluate research institutes and universities as important. Firms point to specific research projects with a limited set of partners as important for knowledge development linked to ongoing firm specific activities. In terms of broader collaborations such as in FME SuSolTec firms point to this as important for foundational knowledge development as well as knowledge of value chain segments which firms themselves are not specialized in and is seen as critical in the long-term. Firms see the value of knowledge sharing in order to understand dynamics in other value chain segments. Some actors however point to out that such partnerships as something they would like to improve, and engage more in, which however can be hampered by cost issues.

Issues linked to digitalization, machine learning and automation are highlighted as important ways to increase efficiency in production and cut costs. In these areas actors however don't see off-the-shelf solutions as feasible, but rather see the need to develop them linked to fit firm operational profile. For instance, the development and introduction of monitoring and control system for pulling silicon ingots, in collaboration between firms and R&D actors, has contributed to increase the efficiency in the production process. Some actors also point to digitalization and automation as areas that would benefit from further development and strengthening.

6.3 Guidance of the search

Price declines and expectations of PV playing a key role in the future energy mix globally are general trends which motivate firm entry. Being engaged in the development of green and sustainable solutions, is also a frequently mentioned factor across segments. This is mirrored in Figure 11, which shows that the majority of firms report to largely or completely agree that contributing to combating climate change is a motivation to be in the PV industry.

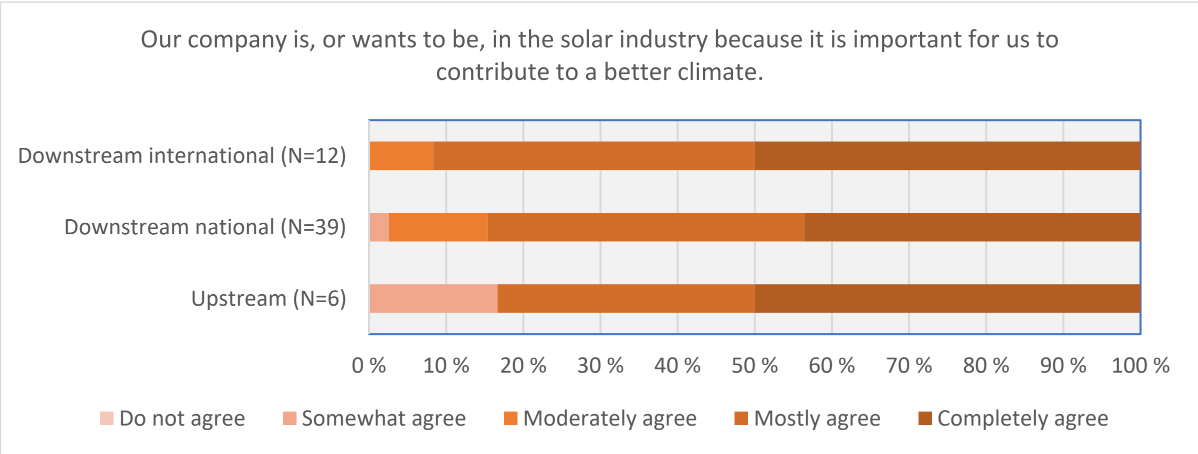

Figure 11: Climate related motivations to be in PV industry (Source: survey)

Based on our interview data we find that factors related to markets are further important drivers. Policies and regulations that influence the size and dynamic of international markets are frequently mentioned as important both by upstream and downstream international firms. Policies, regulations and public incentives within the domestic realm are however much less mentioned, when it comes to being a decisive and direct influence on the direction of search and motivation for entry. When Norwegian policy related issues are mentioned in relation to direction of search, this mainly concerns the lack of (persistent) public sector incentives. Figure 12 mirrors the differences in incentives in terms of PV being an industry with good financial opportunities, between nationally and internationally oriented firms. The majority of firms targeting the national market report not to agree or only somewhat agree that financial opportunities is a motivation to be in the PV industry. The majority of firms with an international orientation on the other hand report financial opportunities as an important motivation.

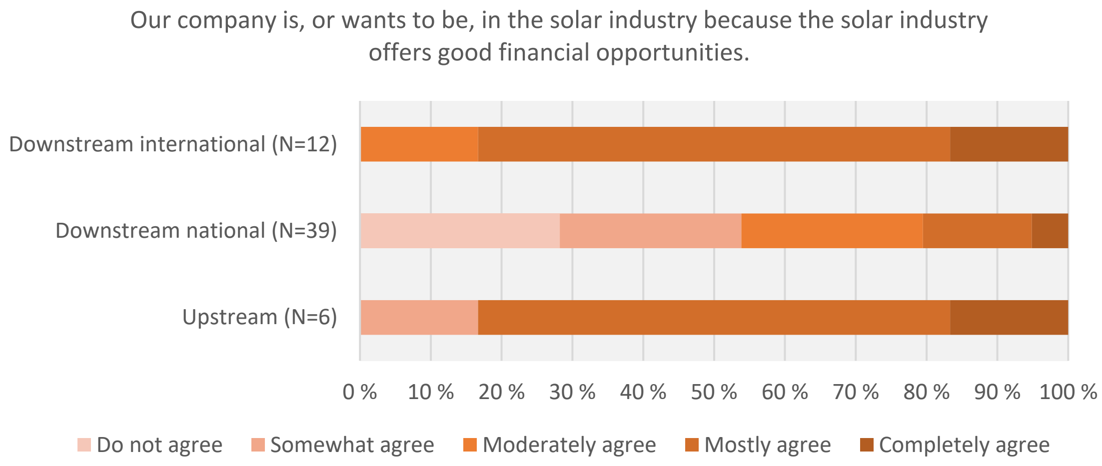

Figure 12: Financial opportunities as motivation to be in the PV industry (Source: survey)

6.3.1 Downstream - National

One aspect that companies find motivational to work with solar PV is the environmental aspect of the technology, 'to be green', where several different types of buildings, like public buildings, municipal buildings, private houses and schools, now consider to adopt some kind of a solar energy system. Similarly, the reduction of the carbon footprint within a certain period could be a company's target within solar PV. It is also believed that working with and managing energy systems could be a motivational factor to enter the solar PV market. Building competence around solar PV to attract new job positions in Norway, is also among the motivational factors for companies' development in this market.

Additionally, companies search for green storage solutions that could be combined with PV systems. Apart from battery technology, thermal storage systems is an area of search for solar PV companies where the search is focused on exploring energy storage solutions. Also, a field that is considered underdeveloped is the digitalization processes of solar PV. Companies use progressive approaches to develop digitalization platforms which merges the interfaces of existing PV systems into one communication platform for energy management. On the other hand, two companies chose not to focus on solar PV but rather to focus on a different sector of solar energy. For instance, a company with experience in solar installations in the past, is now focusing on solar thermal.

6.3.2 Downstream - International

Aside from pointing to large expectations for PV growth internationally, firms also point to clean energy demand among end-users and consumers as an important motivation for entry. One key driver and motivation for firms that operate internationally relates to energy poverty. Several firms engage in supplying PV based solutions in low-income economies in which large shares of populations do not have access to electricity. Given the rapid cost declines, PV is seen as a versatile and cheap solution to secure energy access while contributing to mitigate climate change. This combination of solving sustainable development goals (SDGs) is also a key motivation for actors such as NORAD and Norfund to increasingly support PV as part of developmental efforts. While energy related aid investments traditionally have been focused on hydropower, given Norway´s history in this sector, PV has become a viable solution. We do however observe a bias, which influences the direction of search within the PV TIS towards large scale installations in these market segments. As such, large scale PV solutions seem to have aligned better with aid institutions. Actors working with decentralized solutions experience it more challenging to tap into the Norwegian aid mechanisms, which are key to leveraging finance. A key reason being that decentralized solutions typically involve many customers and projects, as opposed to large scale projects which typically only involve few and large customers. Firms working with decentralized solutions however also report that there are large market opportunities, and point to their solutions as ideal in settings without grid access, and recent changes in Norfund`s approach has also opened up for support of smaller projects as well. Despite the bias towards large scale, actors across the board do however seem to agree on the need for both small and large installations in low-income economies.

A further factor that has strengthened the direction of search towards decentralized solutions is the developments in adjacent technologies such as digital payment methods, LED-lights and energy efficiency measures, as well as battery storage. The ability to use digital solutions to secure payments, such as so-called Pay-Go models where customers make small down payments over time is for instance one enabling market entry and customer interaction.

6.3.3 Upstream

An important motivation for upstream firms is linked to sustainability and engaging in green industry development. Firms point out that they want to be engaged in business which can contribute to solve grand challenges related to climate and sustainability.

A further strong driver for guidance of search relates to customers' needs and developments of markets, which many actors point to as an important influence. This can manifest itself in different ways. In some instances, customers articulate demands towards potential suppliers, making B2B interaction one important mechanism. This can for instance concern firms wanting to make production more efficient by seeking collaboration with potential suppliers. In other instances, firms see opportunities in addressing unsolved problems in the industry by developing both new and improved products, components or processes. For instance, this can be developing new or improved processes for silicon production or ingot/wafer production, new or modified products that go into the PV manufacturing chain such as adhesives or crucibles. Generally, as PV is still a highly dynamic industry, firms point to seeing opportunities to do things more cheaply and efficiently as strong motivations to have entered the industry. However, the development in market formation in the upstream module value chain has also impacted direction of search negatively. Due to the shift in dominance of manufacturing capacity towards Asia, some actors express a hesitance towards entering PV, and for this reason also express search towards other industries than PV.

In a broader context, some actors point to what they see as a lack of industrial strategies for PV. Given that the development of new products and services are long-term processes, and remaining competitive also relies on constant improvements, firms point to the benefits of more stable framework and support mechanisms. This naturally connects to the political context, and some actors express experiencing an uneven playing field compared to other Norwegian industries, such as oil and gas, in terms of having stable framework conditions.

In the upstream value chain direction of search within the TIS relates to different types of technology trajectories in the module manufacturing chain, and particularly to cell efficiency and thus material types. A frequently mentioned issue for instance is the shift from multi- to mono-crystalline Silicon, which actors expect to proceed further. Therefore, the adaptation of products and processes to this shift is highlighted as important, and the knowledge and capabilities to do this is typically referred to as strong.

6.4 Market formation

Market formation dynamics for Norwegian firms strongly depends on value chain position, and the dynamics occurring in the up- and downstream value chain has different implications for different firms. The geographic orientation of markets of Norwegian PV firms was depicted in Figure 3, and showed Norwegian firms having both national and international activities.

Since upstream firms have an international orientation, these firms experience a challenging competitive and price pressure situation, which in turn has resulted in strong cost cutting needs to remain competitive. In downstream segments these price reductions open up new opportunities and drive entry towards PV. Moreover, the capacity of Norwegian upstream suppliers by far outpaces capacity in the Norwegian home market, and markets for solar PV generally are larger abroad. Combined with the fact that the Norwegian market remains small, this means that a range of Norwegian firms have their activities related to accessing international markets. Overall, this implies that market formation for Norwegian firms occurs in both national and international markets, where the latter are strongly influenced by market shaping factors outside of the national market and political realm.

6.4.1 Downstream – National

6.4.1.1 Main products and services

All companies have been involved with installations of solar PV systems and the majority of them are active today, since this is (one of) their primary activity/ies. Firms in our sample work in a variation of market segments. For instance, one company works on solar installations for commercial buildings, one works on solar installations for farmers, industrial and some private buildings, one is active on solar installations for various building types, while several are/or have been active on solar installations.

6.4.1.2 Market growth

The solar PV market is growing slowly for many years, with many new actors entering the market. After reaching a peak point 2 years ago, the solar PV market is more stable now. In the beginning, the market was focused on private households that might was combined with other low-carbon solutions, like an electric car. Now, it is believed that the market is difficult for small, solar installation companies, since the solar PV market is becoming more focused and market leaders of private households outsource projects to solar installations. Still, the market is considered new with no clear or strong focus on a future direction. One belief is that traditional PV modules will continue to dominate the market, as well as BIPV regardless its cost.

The last year of the pandemic has been challenging the solar PV market, and the market is expected continue to grow more in the future. During this period, it is believed that the prices have been almost stabilized. The effect of the pandemic in solar PV industry is believed to have a positive side where only the 'serious' solar companies, with customer-driven services, survived the crisis. Furthermore, Norway is considered a difficult market as companies are continuously pressing the prices down due to their customers' demands. The product quality on the other hand, is not in the list of customers' main interests. Electricity prices are considered low and this could be a factor that decelerates the market growth.

The role of policies is considered to be in placing regulations that open up the industry and play a more supportive role in the future. A few companies however have differing views on this and believe that the market could evolve even without subsidies. The reporting systems of the policy support schemes are questioned along with the existing laws and regulations of market that are more suitable for centralized power. This relates to the differences between centralized and decentralized power when reporting systems of the policy support schemes are involved. In the case of decentralized power that is produced in every roof, reporting becomes more challenging.

The environmental side of solar PV is considered as the driving force of this market more than the financial side. However, there is a difference on the environmental impact among diverse solar panels. The environmental impact depends on the materials and production process of a panel. In addition there is a perception of some increased public knowledge and awareness of solar energy and solar installations and it is easier to approach potential customers and talk about solar energy than before. Public buildings, municipal buildings, old people's homes, schools are examples of areas of the built environment where actors consider installing some kind of solar energy system.

6.4.1.3 Policy support

The past conditions of the solar PV market where it was driven by the subsidies has ended. Now, most subsidies are gone and this contributes to slowing down the market growth. It is believed that there is a divide between the government's ambitions regarding support on solar PV and the implementation bodies, where the government states its support to the green initiatives, but the implementation bodies have their own criteria of subsidies' distribution. For example, large scale wind parks potentially could get support while private customers could be excluded from the support schemes.

Certain policy mechanisms have a specific target group. For example, Enova is considered to support solar PV installations for private housing mostly and for big projects, if they involve a new technology. Moreover, Innovasjon Norge is considered to potentially support solar farms, while support from municipalities, like Oslo municipality, could provide support for commercial buildings.

The level of experience in companies and their focus on product development might attract certain financial support. Companies believe that it would be an advantage to have a well-defined support scheme, both in terms of financial capital and duration. Additionally, firms express the need to align the duration of support with the product development cycle, and not, for instance, to stop when a new technology has been demonstrated.

6.4.2 Downstream - International

Firms in this segment point to the importance of understanding the local conditions of markets and factors which influence them. This can relate to countries` overall climate and political ambitions, as well as regulatory issues such as land rights, taxation and complying with ethical standards. Moreover, this also concerns developing an understanding of how demand is articulated in particular types of contexts. For instance, low-income economies, particularly in Africa, harbor large populations living in energy poverty, i.e. without access to electricity. Both large- and small-scale solutions are relevant in these contexts, but customers are typically very different. For utility scale installations the customer is typically a (state) utility, while for small-scale customers are households and private customers. Utility scale solutions are typically based on long-term contracts which require extensive legal work to secure power purchasing agreements (PPAs) and project financing. For households, the energy demand in many cases is reported to not be very large, and solutions thus need to be tailored. However, while there in essence is a large market potential in developing economies, market formation is challenged by issues related to capital access and purchasing power, discussed under resource mobilization. The energy demands are huge, and in light of climate issues, new added capacities should come from renewables. Low-income families may however not have access to capital services, which means the market needs are present, but need support or novel pricing mechanisms, such as those discussed under entrepreneurial experimentation.

In order to maneuver the conditions that influence market formation in downstream segments, firms point to the importance of establishing a local presence. Several actors operating in low-income economies point to the importance of previous knowledge and networks in these markets, in order to establish trustful relations to potential customers. Such networks can be built upon previous business relations in other sectors, via embassies or through aid organizations such as the UN. Several actors also point to the need to build up local offices, with local employees.

6.4.3 Upstream

Beyond the general market trends in terms overall growth and price drops, there are several factors which contribute to shape the market and the dynamics of competition in global value chains, and the associated geographical dimensions of markets. The entry and subsequent Chinese dominance in PV is one key factor frequently mentioned by firms in the upstream module value chain. Interview material suggests that this shift has had several critical implications for Norwegian firms. First, there is fierce price competition, and Norwegian firms depict a situation with an uneven playing field, where they suspect Chinese competitors to sell products below cost. Second, a result of the shift towards China is that few customers of products and services remain outside of China. Moreover, the market is characterized by a high degree of entry and exit, which creates a chaotic situation. This is reported in some cases to limit the ability to build trustful buyer-supplier collaborations necessary for continuous innovation, as described under knowledge development. Fourth, firms differ in whether they report to sell products to Chinese customers. However, even those that do have Chinese customers report less close-knit relations to customers. Those that do not sell to China report fears of intellectual property rights (IPR) infringements as a main reason not to enter. Language and cultural barriers are also reportedly limiting closer collaboration. Fifth, given the size of the Chinese deployment market, dynamics in this market has potential repercussions for the entire value chain. Sixth, firms also expect China to become the main supplier of manufacturing equipment, which earlier was a European stronghold.

Some upstream firms have however maintained customer relations with firms outside of China, for instance to customers in the U.S. Such relations are pointed out to be critical, as discussed under knowledge development, given that they facilitate opportunities for innovation and improvements in manufacturing efficiency necessary to remain competitive. Firms also express expectations that a new geographic shift may arise in the future, with a potential industry resurgence in the EU, amongst others. Recent initiatives, such as that of the newly established European Solar Manufacturing Council (ESMC) works towards such an end and is comprised of European manufacturing firms, and includes Norwegian firms. A European industry resurgence could potentially open up new market opportunities for Norwegian firms, particularly connected to sustainable and environmentally friendly production. As will be discussed under legitimation, a key competitive asset of Norwegian upstream suppliers is the ability to base production of renewable energy, which contributes to a low carbon footprint on materials and products. Some markets, such as the French and South Korean, put a premium on such products, and Norwegian firms therefore experience a competitive advantage in such markets.

6.5 Legitimation

With regards to general social acceptance of PV in Norway, a survey executed by Kantar, shows that a large proportion (89%) of the Norwegian population are positive towards solar energy as an energy source, which is rated higher than other renewable energy technologies such as wind power (Kantar, 2020). During interviews, some firms however, point out that they experience a limited attention and knowledge about PV. As a general indicator of attention to PV, we searched news media and parliamentary databases to observe the frequency of mentioning of solar energy compared to other renewable energy technologies in Norway. Solar energy is awarded with less than other renewable energy technologies. Figures 13 and 14 depict mentions of renewable energy technologies in Norwegian Parliament (fig 13) and in Norwegian media (fig 14). These are not direct indicators of legitimacy, given that the content of media and parliamentary mentions have not been assessed qualitatively to judge whether for instance mentions are linked to particular (negative or positive) views on PV and other technologies. However, we believe the figures give an indication of the lower political and media attention that PV has received compared to other renewable technologies.

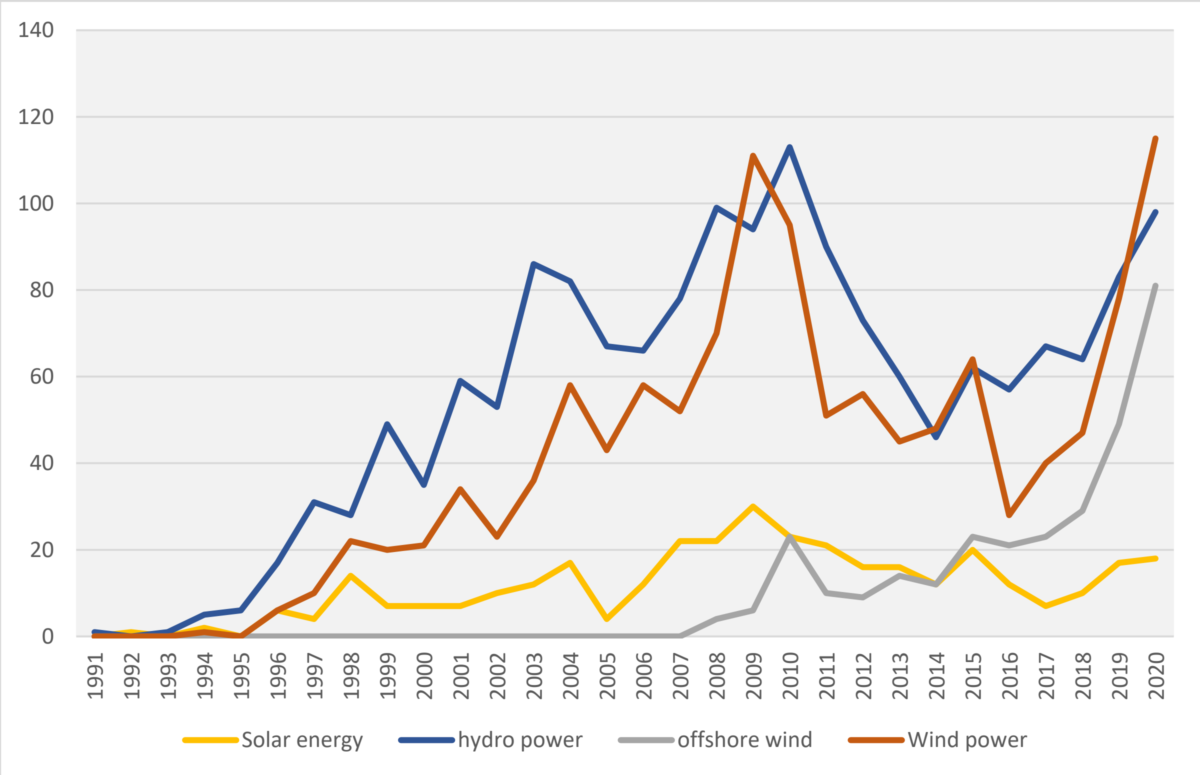

Figure 13: Mentions of solar energy, hydro power, offshore wind and wind power in Norwegian Parliament. (Source: Stortinget.no)

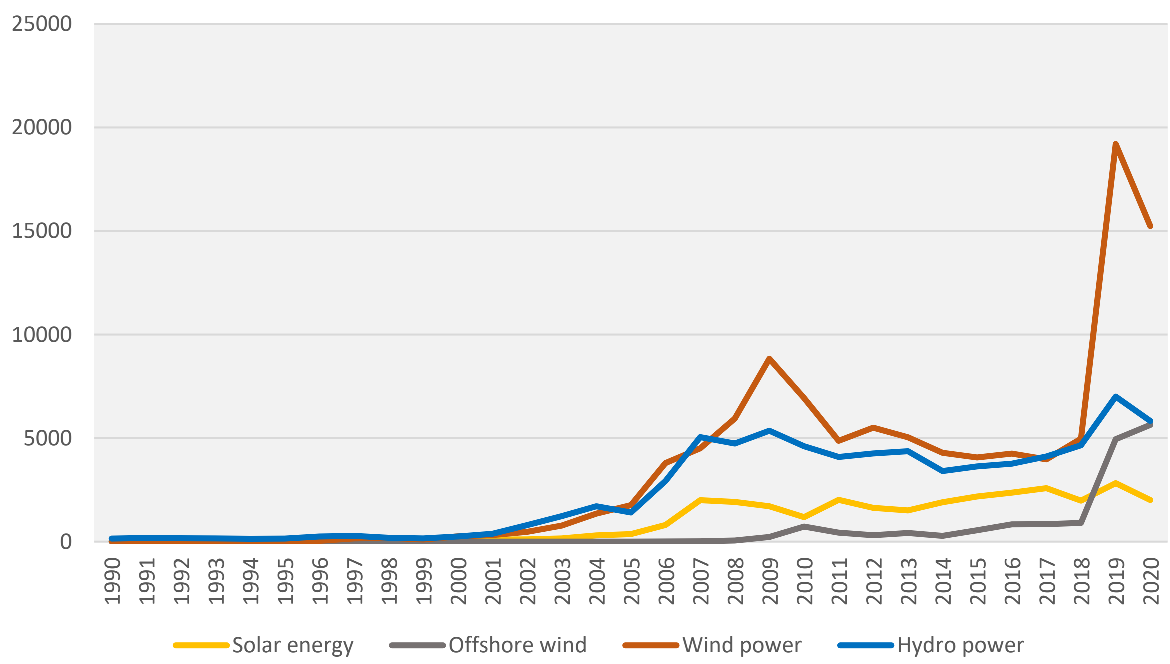

Figure 14: Mentions of solar energy, offshore wind, wind power and hydro power in Norwegian media (including newspapers, radio and TV). (Source: Retriever.no)

Legitimation is also about how a technology aligns with policies and regulations, i.e. whether these fit the new technology and play a supportive role. In order to assess this type of legitimacy in the survey, we asked the firms how satisfied they were with existing policies. The results shown in Figure

15 display a clear difference between up- and downstream firms, with upstream firms showing a higher level of satisfaction than downstream, which suggests a stronger misalignment with existing policies and regulations for the downstream firms. In the downstream segment firms with a national orientation show the lowest level of satisfaction.

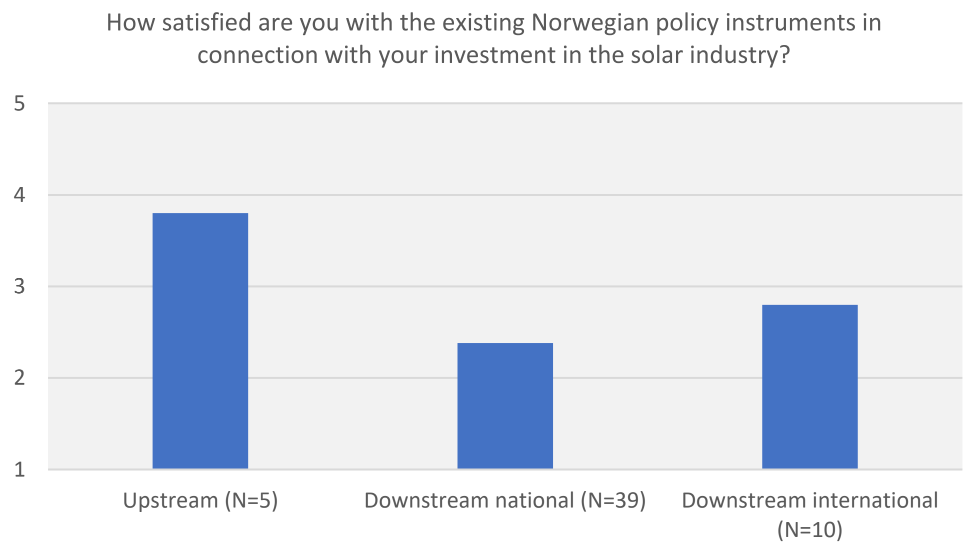

Figure 15: Satisfaction with existing Norwegian policies (Source: own survey)

Figure 16 displays how firms rate the importance of a selected set of Norwegian policy instruments. Again, downstream national firms rate these with a consistently lower degree of importance than upstream and downstream international firms. This suggests a misalignment with existing policies, particularly amongst the firms with a national orientation. For instance, investment support could have been expected to be highly important among these firms. The fact that this is reported as quite unimportant, could be seen to mirror the challenges linked to policy support discussed under market formation for these firms. The high importance of R&D support reported by upstream firms, is also mirrored in the interview material. Upstream activities thus could be seen to align better with the prevailing Norwegian approach to support renewables with instruments targeting technology development (Hanson et al., 2011).

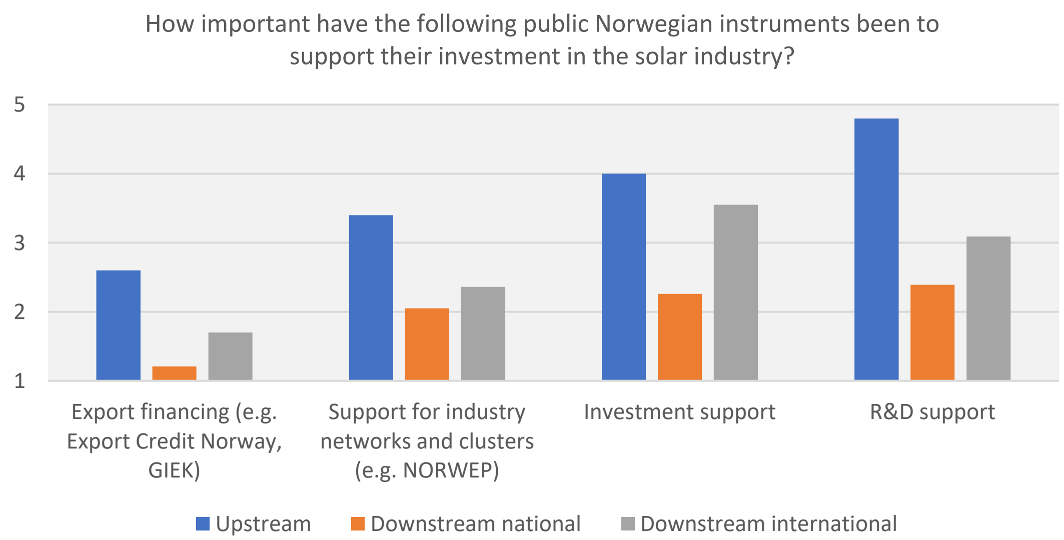

Figure 16: Importance of selected Norwegian policy instruments (Source: survey)

6.5.1 Downstream - National

Following regulations for the Norwegian solar PV industry is critical. The supply companies acknowledge that any equipment that is delivered to Norway should be translated in a Scandinavian language with a Norwegian user manual for installation.

Other regulations refer to CO_2 footprint. The standards of carbon footprint and the reporting of such PV products is not well developed, but also they are not well implemented by the producers of the solar PV products. First, the process of setting carbon footprint standards for solar PV products involves the entire process from the production to the end user. It is considered difficult to push the module suppliers to answer questions for carbon footprint standards and this is a general, unsolved problem for the solar industry globally. Second, many module producers don't have available data regarding the CO_2 footprint on the solar panels. Many producers claim to be 'green' but it's difficult to compare and find information on the CO_2 footprint. Such information will however be useful for customers and end-users to learn about a product's CO_2 footprint and to what extent it is environmentally friendly.

In addition, there are lots of different products that change rapidly, therefore certifying a panel is a difficult process. This also leads to the limited ability of the companies to answer their customers' questions about CO_2 carbon footprint. However, there is a growing interest for information about carbon footprint of the solar panels.

It is believed that the focus should be on the right kind of solar panels that have the best CO_2 footprint. Awareness should be raised regarding the positive impact of the solar panels for the environment. A few customers are starting to have a concern regarding the carbon footprint, when they buy PV modules, but most of them are satisfied by the fact that solar is an environmentally friendly technology on its own.

Companies try to promote low carbon footprint modules but it is reported to be extremely difficult. The majority of the customers/ end users don't ask for it. While actors would like to see a low carbon footprint this is not valued, since there are no incentives to focus on low carbon footprint modules. Also, the availability of low carbon modules is low and those that have focused on low carbon modules earlier have stopped. Third, it's difficult to actually get modules with low carbon footprint because even if the modules have a certification, it is difficult to check the carbon footprint, and if the correct modules have been delivered. Despite this, some companies try to get their products certified for carbon footprint, securing that the products are based on the best CO_2 friendly materials in the market.

6.5.2 Downstream - International

Norwegian firms in international markets, highlight the need for understanding and aligning with the local institutional conditions in the markets that they target. A key issue mentioned in that regard relates to land use and permitting, which is highly important given that these are infrastructures typically built to last several decades, and that PV projects may occupy quite large areas. Complying with regulatory frameworks is therefore highly important, and these are reported to be time consuming processes in some instances. Actors that target markets in low-income countries however note that this can be particularly challenging, amongst others due to corruption and unpredictable institutions. Actors report strong focus on performing due-diligence checks to address such issues, which amongst others includes checking the history of partners and land-owners, issues related to land rights and endangered species. This constitutes one of several risk factors, which in turn contribute to make capital costs large, since lenders to activities in these markets typically price in higher risks, as discussed under resource mobilization.

In relation to the high capital costs a frequently mentioned issue was therefore the strengthening of Norwegian guarantee mechanisms which could help to bring down capital costs. Actors point out that they themselves, and in collaboration with other firms, NGOs and the solar energy cluster have been engaged in trying to influence the regulations for credit guarantees. Actors related to decentralized solutions point to having experienced a mismatch with how guarantee mechanisms have been operationalized. Such actors have previously experienced challenges with getting such guarantees, and that they were highly resource demanding to apply for in terms of performing due diligence, which is more challenging and resource demanding to do for many smaller projects. While actors involved in both centralized and decentralized solutions agree on the need for both types in order to meet electrification, developmental and climate objectives, actors engaged in decentralized solutions experience a greater mismatch with existing institutions.

6.5.3 Upstream

Upstream firms mention legitimacy and acceptance in relation to performance characteristics in buyer-supplier relationships as highly important. Firms report on the importance of verification of products, including use of third parties to verify the performance characteristics of products/service to increase business legitimacy. This can for instance be novel types of materials or production methods.

Firms report that their activities typically align well with the way current policy instruments, such as R&D support is operationalized. The higher level of satisfaction with Norwegian policies applicable and related to PV, as illustrated in Figure 16 also mirrors this. However, growth and development in the PV industry is dependent on mobilization of financial resources also in terms of private investors and banks, particularly in order to scale, but this depends on legitimation. Banks and lenders and private investors have viewed PV with a certain degree of skepticism, particularly given the heavy competition from China.

Upstream actors also highlight the importance of low CO_2 emissions related to their production as a key legitimating factor. As mentioned, only a few markets so far incentivize the use of PV modules with lower carbon footprint. Environmentally friendly production is however a comparative advantage, which sets them apart from Chinese competitors. Norwegian firms have therefore been involved in setting up the European Solar Manufacturing Council in order to make sustainability part of the initiatives to create a new industry resurgence in Europe, and use this platform to communicate towards EU policy makers. Firms such as Norsun and REC have recently also been rewarded with environmental product declarations (EPDs) for their products (Solenergiklyngen, 2021).

6.6 Resource mobilization

Resource mobilization is discussed as a process associated with weaknesses. In fact, many firms both in up- and downstream segments, when asked about key barriers or factors that could facilitate growth and strengthening of industrial activity, point towards a stronger mobilization of financial resources as critical. Actors in the national market point to lacking public incentives for PV deployment. Actors that target international markets both in up- and downstream segments point to a better access to risk-mitigating capital as a potential solution, and point to towards the public sector to be such a risk taker. They further report that stronger guarantee mechanisms could be a potential factor to help address the challenges with securing private investments and loans and thereby strengthen resource mobilization.

6.6.1 Downstream - national

Human resources are considered one of the success factors in solar industry, where competent engineers that either are employed by or collaborate with a solar PV company, offer high-quality services to their customers.

Mobilization of financial resources is critical for solar PV. For quite some time a part of the solar PV market was driven by subsidies, but now, most subsidies for companies no longer exist for solar installations. Many Norwegian policies, like Enova and Skattefunn, offer financial support schemes, according to certain rules. For example, Enova provide financial resources for solar installations in private houses, while in bigger projects an innovative technology should be involved in addition. Other Norwegian support organisations, like Innovasjon Norge, potentially provide financial resources to solar farms, however the focus might be more on supporting less experienced applicants, who focus on product development. In addition, municipalities like municipality of Oslo, provide support to commercial buildings. Companies could also receive support from EU projects.

Companies however express that Norwegian policies haven't been very efficient, in terms of the long and slow processes when applying for financial resources. They also think that there are differences between the government's ambitions regarding support for solar PV and the implementation bodies. For instance, they could provide large support for a new wind park, but the private customer could be excluded from the support schemes. This focus on large projects is considered to absorb the majority of resources while small entities in the market, like single customers, are seen to also need to receive the same support for the market to grow.

Furthermore, companies try to get support for introducing new solar panel technologies in Norway but they find that the process stops due to the lack of evaluators' knowledge. One example refers to the projects of bifacial solar modules, or different glass technologies that would be more beneficial in the northern regions. Also, variation between different technologies, such as BIPV and floating solar farms, are in some instances considered wrongfully evaluated. Another barrier to resource mobilization is the duration of the financial support. For instance, the financial support might stop just after a new technology has been demonstrated, without having time for testing it. A further barrier is that financial support for PV is seen as lower than for other industries.

Firms therefore see the need to change existing or develop new types of similar policies or frameworks. Companies suggest that it would be advantageous to receive a well-defined support both in terms of financial capital and duration. The Swedish policy for the solar energy market is mentioned as an example of a successful model which better defines the duration of the financial support from the beginning, allowing better planning for companies.

6.6.2 Downstream – international

Downstream firms that target markets in low-income economies, point to mobilization of financial resources as particularly critical, given the large market potential and energy poverty, and subsequent needs for energy access. Most firms point to various types of challenges connected to securing financing for projects and activities. While the drops in PV prices has increased viability substantially also in competition with fossil energy sources, high capital costs are seen as a significant barrier to more rapid diffusion. While operational expenses are significantly lower for PV compared to fossil solutions, initial capital expenditures still can be higher. Many actors attribute the high cost of capital in low-income countries to exacerbate this. Lenders typically price in high degrees or risks in these markets, which in turn results in the overall costs of a project to increase. Firms for instance mention that they experience international development finance institutions to over-assess the risk profiles of many projects.

Firms operating in low-income economies report that financial resource mobilization from aid and developmental institutions has been important, with both national (Norfund, NORAD) and international sources (International Finance Corporation, etc) being mentioned. Norwegian institutions themselves contribute to resource mobilization in low-income economies, by supporting project development and as investors in PV projects. This is however not necessarily tied to activities of Norwegian firms, as the mechanisms employed are technology neutral and the applying firms do not need to be Norwegian. Moreover, such funding isn't mainly deployed to trigger innovation and technology development, but rather the development of projects.

Actors point to the need for leveraging more and lower cost capital, and one frequently discussed issue to facilitate this is the strengthening of guarantee mechanisms, both in terms of volume as well as in terms of applicability (i.e. also open more opportunities for decentralized solutions). Actors generally point to this as critical for leveraging more investments in PV in low-income economies. Such guarantees are seen to potentially leverage more private capital, with lower interest rates than those typically seen available at development banks. This is mentioned by firms working with both centralized and decentralized solutions.

In terms of human resources, actors point out the need to build up human resources in the markets that firms target. Employees with knowledge and experience from the particular markets that firms are active in is generally mentioned as a necessity for such firms. In some instances, this can lead to challenges connected to securing funding from Norwegian support organizations, given that these might raise questions related to value creation and employment in Norway.

Finally, land resources are seen as a key resource, particularly for firms operating in utility scale. Land rights, and compliance with regulations, as discussed under legitimation, are mentioned as particularly important in relation to securing access to such resources.

6.6.3 Upstream

In the upstream segment actors point to public support for knowledge and technology development as important, and in general point out that they are satisfied and dependent on this support. Funding from the Norwegian Research Council, Innovation Norway, Enova and EU is frequently mentioned. Such public support is mentioned as particularly important, since actors, both established firms and start-ups, mention continuous knowledge development and application of this knowledge for entrepreneurial experimentation as central for competitiveness. While general satisfaction with public support for knowledge and technology development is expressed, some actors point out that experimentation and piloting for more large-scale projects is challenging to secure within the Norwegian system. These actors point out that they perceive their competitors abroad to have better access to such resources.

Public support for mobilization of financial resources beyond targeting knowledge development specifically, such as investment support for infrastructure, loans and export financing is also mentioned as important. Firms also mention that they themselves invest heavily in for instance machinery, equipment and human resources, thereby contributing to resource mobilization. However, given the importance of scaling up production capacities, firms point to challenges of raising sufficient levels of investments, and challenges related to legitimation influence this. In turn, challenges linked to raising private capital can in turn make it more challenging to align with existing policies in Norway and EU, which often mandates a certain degree of private capital being mobilized alongside public support.

Firms in the upstream segment also mention other key resources where being location in Norway contributes to a competitive advantage. First, access to sufficient renewable energy at competitive prices is important for competitiveness overall for those that rely on energy intensive processes. Access to cheap renewable energy also contributes as a competitive advantage of offering products with a low carbon footprint in markets that put a premium on such products, as discussed under market formation. Firms also express that increasing power prices could be a challenge to competitiveness, pointing to periods with higher spot prices as challenging. Second, access to cooling water for manufacturing processes is mentioned as an advantage compared to competitors located in regions without such access.

6.7 Key success factors in the downstream national segment

For the downstream national segment, the key success factors in the solar PV market are considered the energy saving cost and the green initiative. However, the investment in solar PV is not considered applicable to all cases, in terms of ROI, but should be evaluated individually. From the companies' perspective and their services, success factors in this market are considered the competent employees, cooperation among companies, as well as to provide concrete information to the customers, and quality installations. Companies consider that the beginning of the 'green shift' started with the electric car that affects the use of solar PV energy. Therefore, it is considered important to offer complete solutions for customers, from product supply to installation of solar PV system and connection to the grid. From the customers' perspective, success in this industry is considered to consume your own solar energy, and the tailoring of solar PV installations to customers' needs is important.

6.8 Key barriers in the downstream national segment

Lack of consistency in terms of the subsidies provided by the government is seen as a key barrier. Additionally, governmental standards and regulations limit the flexibility in solar PV installation capacity. Consequently, companies and their customers cannot build as much as they would like, since there are restrictions from the NVE especially for big solar plants. Other barriers include problems with the electricity grid and cables, especially for large installations where the production of big PV plants is higher than the capacity in the electricity grid. In addition, actors report that there is prejudice around solar energy in that it is believed that Norway is in the dark side of the globe with insufficient sunshine. Therefore, the general knowledge of the customers in the market and in the potential of solar PV is considered a barrier. Actors report that most of the customers don't realize the potential of solar PV and that many are surprised by the cheap renewable energy that could compete with other renewable sources.

6.9 Key drivers in the downstream international segment

Rapid and large price declines are mentioned as a highly important driver. Solar is expected to become the cheapest technology and firms thus see it as important to be engaged in solar if they want to engage in renewables internationally. Preexisting presence, networks and relations in the countries that actors are present in is highlighted as important related to market and customer access, and understanding of user needs. Aid related organizations are frequently mentioned as important customers and enablers of further market access as well as having employees that have direct access and knowledge of specific contexts. Firms also refer to having conscious strategies to build organizations with different nationalities, particularly those from target markets. This enables an understanding of target markets and user needs. Business models, and capability to change is highlighted as important in relation to remaining competitive alongside capabilities to develop technological solutions that suit user needs in low-income countries. Ability to scale, and persistence to develop ideas is mentioned as particularly important among startups. Strong competition also in this segment, and capability to constantly develop solutions is highlighted as important alongside recognition and trust in the market.

6.10 Key barriers in the downstream international segment

Capital access and financial risks is mentioned as a key barrier. For startup firms that have little private capital and depend on building a portfolio and pipeline of projects, capital access is seen as challenging. Small firms working with small-scale decentralized solutions experience challenges in terms of attracting sufficient private capital to leverage support from Norwegian support organization. Skepticism towards low-income countries both among public and private actors that potentially could contribute to mobilize financial resources is mentioned as a key barrier. Firms in this segment also experience low awareness. Technology characteristics of PV such as simplicity, modularity and associated low entry barriers is mentioned to contribute to a highly competitive environment. Getting land rights can be time consuming and getting them quickly enough is mentioned as important.

6.11 Key drivers in the upstream segment

Norway has a good culture for technology development, in terms of being unhierarchical and oriented towards collaboration, internally in firms, between organization and between private and public actors. This enables an open dialogue about which type of solutions that work both in policy and technological terms, which is favorable to rapid development. Norwegian actors have had the capabilities to deliver quality products and thereby be positioned in advanced niches with demanding customers that push suppliers, which in turn contributes to having a competitive edge. Process development and ability to reduce costs is seen as a further driver. Having a low CO_2 footprint gives further advantage in certain markets, and competitive edge against China. Quality of raw-materials and the competences and capabilities to process them is mentioned as important. Access to cheap electricity and cooling water are seen as key resources, as discussed under resource mobilization. Increase in power prices is seen as a potential risk factor.

6.12 Key barriers in the upstream segment

Having a small home market means that Norwegian upstream market are dependent on what trade partners do. Competition with China is a key barrier given what is seen as an uneven playing field, and an unstable market with much entry and exit, which challenges the opportunities to build the necessary close and trustful user-producer relations. Access to capital is seen as a as key barrier particularly related to important upscaling measures, as discussed under resource mobilization. Resource mobilization is in turn affected by Chinese competition and legitimacy issues amongst investors (i.e. skeptical to touch solar given previous losses in the industry).

7 Conclusions – strengths and weaknesses in the innovation system

Based on a technological innovation system analysis this report has explored the conditions for Norway to engage in the production and use of solar PV technology, both nationally and globally. Solar PV has grown rapidly globally, with expectations to be the most important renewable energy source in years to come. Nationally, PV installations remain small, albeit with growth in installations and number of firms engaged in the Norwegian market in recent years. Overall, the opportunity space for Norwegian firms therefore is large both in the global and national realm.

We observed that the Norwegian PV industry is highly varied, both in terms of value chain position and type of market. We used these dimensions to categorize the firms, and ended up with three main groups; downstream national, downstream international and upstream. In all three segments we see both strengths and weakness, as summarized below.

7.1 Scaling of experiments

We observe a high degree of experimentation, given the growing entry of firms that report to continuously work with new or improved products and services. This is occurring across the segments and is a strength in the system. In the upstream segment firms are reducing costs, and working to enhance efficiency in production. Scaling up is reported to be of critical importance in this segment, but this is associated with challenges to secure financial resources. Supporting the strengths in experimentation by ensuring to harness the potential for upscaling for Norwegian actors is important in order to remain competitive in international markets. In the downstream international segment several new entrants experiment with new business models to target low-income countries, and such experiments could be strengthened by strengthening access to financial resources. In the downstream national segment actors express concerns with support mechanisms that do not go beyond the initial phase of technology development.

7.2 Mobilization of financial resources

We identify the lack of mobilization of financial resources as a key barrier for many firms. If this is strengthened, it could be expected to provide positive feedback effects on other processes in the system, particularly related to scaling up of experiments, continued knowledge development, as well as the development of the national market and in terms of internationalization. In the downstream segment this relates to stronger incentives for development of the national market, such as persistent support mechanisms, and support that goes beyond early-stage testing would be favorable. In both downstream international and upstream segments export and internationalization is important, and strengthening of credit guarantee schemes are pointed out as important particularly in order to leverage private capital. In the downstream international segment, actors that operate in low-income countries point to high capital costs due to high (perceived) risks amongst financiers as a strong barrier. Strengthened guarantees and private capital could alleviate this and bring down costs.

7.3 Stronger and persistent incentives for PV installations in Norway

In the downstream national segment a range of actors point to their motivations to “go green” and the demands of customers as key incentive mechanisms to enter the PV industry targeting. We did however observe very few references to publicly stimulated incentives to engage in PV. In fact, we observe two major weaknesses in this regard. First, the regulatory environment linked to the use of PV in Norway is a barrier, and relates both to size of potential installation, grid integration as well as reporting issues. Second, the removal of subsidies has stalled market growth in Norway. Addressing both these issues could provide stronger and more persistent incentives for use of PV in Norway, which in turn could strengthen and uphold these motivations amongst users and suppliers. This would be important also in light of Norway`s electrification ambitions, and to realize the expected contributions from PV.

7.4 Increased awareness

Firms point to challenges connected to awareness of the particular solutions that actors are engaged in. This relates both to consumers, policy makers/evaluators, and potential investors. Compared to other renewables, we observe that PV has received less attention in Norway. For the downstream segment heightened awareness and knowledge about what PV could contribute with in the Norwegian context, both amongst potential users as well as in education, could boost legitimacy and as a result also market formation. With regards to downstream international and upstream firms, raising awareness of the role of Norwegian PV firms in terms of emission reduction (both up- and downstream firms) as well as addressing energy poverty issues, would be beneficial.

7.5 Maintain knowledge development and strengthen technology interaction

Since PV is a continuously and rapidly developing field, the strengths in knowledge development should be maintained. Knowledge development is generally evaluated as a strongly performing process, being rewarded with public support. Actors also point to networks that facilitate knowledge sharing such as the FME SuSolTech and the Solar Energy Cluster and should be maintained. Digitalization and automation is frequently mentioned in all segments. In downstream segments, both nationally and internationally, actors speak of digital solutions as (potential) enablers in relation to integration with customers, monitoring and control of systems. Additionally, actors point to important knowledge development linked to interaction with other technologies, such as storage and demand side management. In the upstream segment digitalization is linked to improvement and scaling of manufacturing processes, and further knowledge development is critical to further cutting of costs and competitiveness in high quality segments which Norwegian firms target. However, actors do point to needs to strengthening capabilities and knowledge development in these realms as they could be expected to support further experimentation and scaling of PV.

7.6 Environmentally friendly upstream production

Upstream firms unanimously point to the advantage of supplying products with a lower environmental footprint than competitors, particularly from China. Firms see the ability to base production on cheap renewable energy as an advantage in markets which reward low carbon footprints. While a low carbon footprint is up until now only rewarded in some markets, Norwegian actors would have a strong advantage should the trend of putting a premium on low CO_2 footprints be diffused to other markets. Energy efficient processes, and the introduction of circular economy thinking, also signals further efforts to green production of upstream materials and components. This is a key strength of the Norwegian industry, and a distinguishing trait particularly compared to competitors that rely on production based on fossil fuels. A stronger involvement of Norwegian authorities in attempting to shape regulations and markets to favor products with low carbon footprints, could further leverage the natural competitive advantage of Norwegian firms. We also note that downstream actors report a lack of incentives for deployment of modules low CO_2 footprints in Norway.

7.7 An industrial strategy for solar PV

Finally, actors point to PV as a largely bottom-up developed industry over time. In general, this is a strength, which indicates strong motivations among industry actors for continuous engagement. However, a broader industrial strategy developed by private and public actors in tandem, could contribute to further strengthening the industry, in pursuit of the opportunities they report. Such a strategy could include specific milestones and goals in terms of national and international engagement, and a stepwise specification of the means to achieve this.

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