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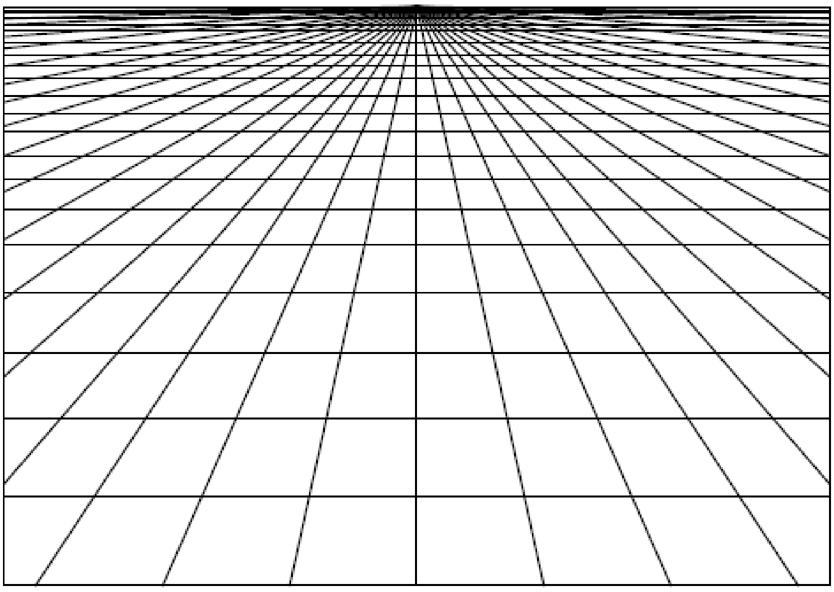
Understanding The Growth of Renewable Technology

The Development of the Norwegian Photovoltaic Innovation System



TIK MASTER THESIS IN INNOVATION, TECHNOLOGY AND KNOWLEDGE

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ABSTRACT

The current global economy is locked into energy systems based on fossil fuels, which blocks the development of renewable energy (RNE) sources. Dealing with climate change and the problems of greenhouse gas emissions (GHG) requires a transition to a low-carbon economy that could help the diffusion of sustainable energy sources such as RNE. Thus, accelerating the diffusion of RNE sources such as photovoltaic energy has been vital for policymakers. During the last two decades, governmental initiatives involving the diffusion of photovoltaic (PV) energy have led up to a global demand for wafers and silicon. Essentially, a photovoltaic industry emerged in Norway to serve a growing demand in the international PV market, which countries such as Japan, Germany, Spain and Italy are willing to subsidise. This thesis seeks to understand the emergence, development and diffusion of the Photovoltaic technology in Norway. The technological innovation system (TIS) framework has been employed in order to analyse innovation dynamic and the diffusion process of the system.

Although, Norway's access to hydropower and lack of PV incentives make it difficult to establish a domestic market, Norwegian companies have built up a significant expertise in PV technology; which covers all spectrum of the value chain. Several of these players are competing in the international market, and are involved in the manufacturing of wafers, silicon, solar cells and modules as well as PV installations. Moreover, a supplying industry with other services and products of the value chain including recycling of silicon, production automation and procurement management emerged to serve both national and international players. This industry has shown that access to (and efficient use of) raw materials and technological expertise are key ingredients for achieving competitive advantage. Norwegian actors operate in a highly competitive global market; currently dominated by low-cost countries such as China, Singapore and Taiwan. Over the last three years, several trends including a global surplus of manufacturing capacity, low production cost leading to module price reductions, the global financial crisis, improvements in production processes and technological advancements have shaped the growth of the Norwegian PV industry. Consequently, Norwegian actors are faced with unfavourable market conditions; leading to reduced production activities, closure of manufacturing plants, downsizing, consolidations, acquisitions and insolvencies. In order to remain competitive these players are expanding their portfolios by developing downstream activities and niche products, improving production processes in order to balance manufacturing costs and moving production to Asian continent.

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ABBREVIATIONS

RNE	Renewable Energy
GHG	Greenhouse Gas Emissions
PV	Photovoltaic
TIS	Technological Innovation System
Norwegian PV TIS	Norwegian Photovoltaic Technological Innovation System
RQs	Research Questions
C-si	Crystalline Silicon Cells
CPV	Concentrating Photovoltaic
Sc-Si	Mono-crystalline Cells
Poly C-Si	Poly-crystalline cells
mc-Si	Multi-crystalline cells
EFG Ribbon	EFG Ribbon Silicon Sheet-defined film
REC	Renewable Energy Corporation
CTO	Conducting layer
a-Si	Amorphous Silicon Cells
CdTe	Cadium Telluride Cells
CIS	Copper-Indum Selenide
CIGS	Copper-Idium –gallium-diselenide Cells
Dye-s Cells	Dye-sensitised cells
OECD	The Organisation for Economic Co-operation and Development
IS	Innovation System
SIS	Sectoral Innovation System
RIS	Regional Innovation System
NTNU	Norwegian University of Science and Technology
UiO	University of Oslo
UiA	University of Aust-Agder
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology
IFE	The Institute for Energy Technology
Norut	The Northern Research Institute Narvik
Solar United	The Norwegian Research Centre of Solar Cell Technology
ITS	Innotech Solar
RCN	The Research Council of Norway
IN	Innovation Norway
SND	The Norwegian Industrial and Regional development Fund
SIVA	The Industrial Development Corporation of Norway
EXPOMAT	Innovation Programmes for Export Oriented material Production and Processing
NYTEK	Innovation Programmed for Effective and Renewable Energy Technologies
PROMAT	Innovation Programme for Processing and material Technology
BIA	The Research programme for User-driven Innovation
RENERGI	Research Programmes for Renewable Energy
NANOMAT	The Research Program for Nanotechnology and New Materials
VAREMAT	Innovation Programmed for Industrial Manufacturing and Materials Conversion
NVE	The Norwegian Water Resources and Energy Directorate
EPUE	European Platform of Universities in Energy Research

EPIA	European Photovoltaic Industry Association
UEA	The European University Association
EII	European Industrial Initiatives
EU PVTP	The European Photovoltaic Technology Platform
SEII	The Solar Europe Initiatives
EC	European Commission
NCE	Nordic Centres of Expertise
NorRen	Norwegian Research School in Renewable Energy
M&A	Merger and Acquisition
NSES	The Norwegian Solar Energy Society
INTPOW	Norwegian Renewable Energy Partners
IEA	The International Energy Agency
IRENA	The International Renewable Energy Agency
NoCE in PV	The Nordic Centre of Excellence in PV
EERA	The European Energy Research Alliance
NERA	Norwegian Energy Research Alliance
EMIRI	Energy Material Industrial Research Initiative
EEA	The European Economic Area
PVPS	Photovoltaic Power Systems Programmes

1. INTRODUCTION

"I have no doubt that we will be successful in harnessing the sun's energy. If sunbeams were weapons of war, we would have had solar energy centuries ago." **George Porter**, Nobel Prize winner in Chemistry, 1967

"We simply must balance our demand for energy with our rapidly shrinking resources. By acting now we can control our future instead of letting the future control us". **Jimmy Carter**

Since the industrial revolution, industrial economic growth has added environmental problems to the global challenges. In today's modern societies, the growth of our global economy depends strongly on fossil fuel energy sources such as oil, gas and coal. This dependency has caused numerous environmental challenges such as pollution, global greenhouse gas (henceforth GHG) emissions and global warming. At the same time, the global supply of energy from fossil fuels is limited, and depends largely on the economic and political prospects of a small group of countries (Suurs, 2009). The growing concerns for energy supply coupled with climate change challenges have directed attentions toward the implementation of sustainable energy policies. Therefore, policymakers have been concerned with implementing policies that will contribute to a sustainable economic growth. During the last two decades, policy initiatives aiming at supporting the diffusion of solar photovoltaic (henceforth PV) in countries such Japan, Germany, Spain, Italy and USA have led to a global demand for wafers and silicon. Essentially, a Norwegian PV industry emerged to serve an international market. Since then, several Norwegian companies have emerged with activities across all spectrum of the value chain.

With a global aggregate size exceeding USD 100 billion per year (RNE 21, 2012), the PV industry is one of the fastest growing energy technologies in the world. Over the last two years, the global PV industry has experienced an annual growth rate of 40% (IEA, 2010) driven by cost reduction, innovation, economic scale and policy instruments. In fact, PV technology has reached grid parity in some regions (IRENA, 2013). This means that innovation in PV technology could help reduce CO2, and induce global economic development. This is mainly because RNE sources can bring energy security by reducing the import dependency of fossil fuels sources and GHG emissions (RNE 21, 2012). Moreover, RNE can induce a sustainable economic development by improving the global health situation as well as energy access in undeveloped regions (ibid) and helped solve the current problems of climate change.

In spite of their potential and increased policy actions, their actual utilisation only supplies 16,7% of the global energy consumption in 2012 (REN12). One contributing explanations is that the industrial economic growth is locked into fossil fuel-based energy systems, through a path-dependent technological and institutional co-evolutionary process (Unruh , 2000). The path-dependency that blocks the development RNE sources is described as “carbon lock-in”. The implication is that incumbent technologies have influence over the institutional infrastructures (Jacobsson & Bergek , 2004). This means that renewable technologies must overcome barriers, and develop competitive advantage in order to compete with incumbent technologies. Similar to the Schumpeter’s concept of "creative destruction" (Schumpeter, 1943), the forces that prevail in fossil fuel-based energy systems need to be broken, if renewable technologies are to prosper. This process of "creative destruction" (or transition) requires the reorganisation of structural and institutional forces that are the basis of the global economic growth, in which fossil fuel-based energy systems are replaced by renewable technologies.

1.1 UNDERSTANDING THE DEVELOPMENT OF A RENEWABLE TECHNOLOGY

Understanding the process of technological change as a social force is an important aspect in understanding the challenge of climate change and the development of RNE sources. This process is shaped by political, social, educational, economic, industrial and institutional factors. This means that technological changes are not external forces of social transformations, but rather a part of them. The development and diffusion of RNE is not just a matter of competition between incumbent technologies, but it is also a matter of changing institutional norms, culture and behaviour during the transformation process. This explains the low share of RNE sources in spite of numerous government actions to increase the share of RNE sources. Therefore, overcoming the current situation of carbon lock-in requires a process of transformation, which can accelerate the diffusion of RNE technologies in our societies. For this transformation to take place, one needs to understand the characteristics of RNE sources in order to comprehend the emergence and transformation of new industries as well as the mechanisms that promote or block their developments.

Several tools can be used to analyse these mechanisms. However, the focus of this thesis is to analyse PV as a technological innovation system. The thesis seeks to understand the dynamic of the Norwegian Photovoltaic technological innovation system (The Norwegian PV TIS). The technological innovation system (henceforth TIS) framework, which is rooted in the literature of innovation system, analyses the evolution of emerging technologies. The framework is particularly suitable for understanding the Norwegian PV TIS, because it focuses on a specific technology (Bergek , et al., 2008b; Bergek & Jacobsson , 2003; Bergek, et al., 2008a; Carlsson & Stankiewicz, 1991; Hekkert , et al., 2007; Negro , et al., 2007). The TIS framework allows us to analyse the structural components that influence the development of a specific technology (or product) and the processes of innovation within the system. Most importantly, it looks at the relationship between innovation processes and structures, and their impacts on the development of the system. Such analysis should allow us to identify the main mechanisms that block or induce the development process of RNE sources. Understanding these mechanisms is essential for implementing suitable policy measures that may effectively and efficiently deal with these mechanisms, and help accelerate the diffusion process (Bergek , et al., 2008b) (Bergek & Jacobsson , 2003) (Bergek, et al., 2008a) (Carlsson & Stankiewicz, 1991) (Hekkert , et al., 2007) (Negro , et al., 2007). By adopting a TIS, this thesis analyses the structural dynamics as well as the innovation processes in the Norwegian PV TIS.

1.2 RESEARCH QUESTIONS

The goals of the thesis and the choice of Norwegian PV TIS are three folded. First, Narula (2002) suggested that the specialisation of Norwegian manufacturing industry, especially in the metallurgic industry involves a structural lock-in and path dependency. However, during the last two decades, a PV manufacturing industry emerged in Norway, through several years of expertise and competence developed from energy intensive industries such as metallurgical and process industries. In addition, there is a general perception that the geographical location of Norway does not provide optimal conditions for the use of PV for power generation. However, studies have indicated that the potential for utilising solar energy in southern Norway is almost as great as places further south in Europe (Good, et al., 2011). Therefore, the aim of the thesis is to understand the emergence of PV TIS in Norway.

Second, access to natural resources, government incentives and regulations, as well as strong industrial clusters are key determinants for growth in RNE sector (World Economic Forum, 2012). Policy measures and incentives such as feed-in tariffs (FITs), tax credits and subsidies have been great policy measures for promoting the diffusion of PV technology, and for stimulating markets in countries such as Germany, Spain, Italy, Portugal, Japan and USA. However, there are no incentives targeted at the diffusion of PV technology in Norway, since the country not dependent on PV. Another contributing explanation is the country's access to hydroelectric power and other RNE sources such biomass and wind power. Still, up until the European financial economic crisis, Norwegian PV companies were at the forefront of the international PV market. Given the fact that most of Norwegian PV products are exported; this thesis seeks to understand the international context of the Norwegian PV TIS.

The focus and aim of this thesis as identified above can be summarised into the following research questions (henceforth RQ):

- ❖ RQ1: How has the Norwegian PV TIS emerged?
- ❖ RQ2: How has the international market influenced the growth of the Norwegian PV TIS?

Third, as the world's third largest exporter of oil and gas (IEA, 2006), Norway must take certain responsibilities in reducing the world CO2 emissions. After all, climate change is a global problem that needs global actions and solutions. However, as a producer of 3,4% of the world's hydroelectricity (IEA, 2012, p. 19) and with hydropower accounting for around 99% of its total electricity production (SSB, 2012), Norway's energy challenges may differ from its European counterparts. In addition, being a resource based-country means that the development of renewable technologies can create great economic opportunities for sustainable development. As such, policymakers must employ a glo-localisation approach toward the development of PV technology. This means that Norway must exploit a specific development adapted to the Norwegian economic climate, while exploring global developments in order to adapt to international demands. This makes it particularly fascinating to identify the underlying processes in which the PV TIS emerged, and the mechanisms that trigger or hamper the development, diffusion and implementation of PV technology in Norway. By studying how PV technology emerged, this thesis seeks to better understand the dynamics of the Norwegian PV TIS, so that knowledge development can be improved, and the electricity consumption patterns can be "unlocked" in order to accelerate the diffusion process and improve the growth of the system. As such, this thesis seeks to understand the relationship between structural elements and innovation processes, their impact on the direction of innovation processes and how they contribute to the development and diffusion of Norwegian PV TIS.

Consequently, two additional RQs emerged in exploring these issues in depth:

- ❖ RQ3: What are the blocking and inducement mechanisms that have determined the development of the Norwegian PV TIS?
- ❖ RQ4: How can the Government contribute to the development of the Norwegian PV TIS?

1.3 THESIS OUTLINE

Chapter 2 provides a short introduction of the economics of PV technology in the global RNE system as well as the principles of PV and the different PV technologies. The chapter will also briefly touch upon the energy situation in Norway and the role of PV in the Norwegian energy system. In chapter 3, the choices of methodological processes are discussed, and the case study approach is justified as a suitable design for answering the RQs. In addition, the chapter provides a detailed overview of the measures taken during the different phases of this study in order to assure the quality of the research conducted in this study. Chapter 4 reviews the theoretical framework chosen for this study. In chapter 5, the empirical data are analysed. First, the scope and boundary of the Norwegian PV TIS are clearly defined. Second, actors, networks and institutions are mapped. Third, the functions of the Norwegian PV TIS are analysed in section 5.3. The functions are assessed, and the strengths and weaknesses of each function are evaluated. The functional pattern as well as overall dynamic and goal of the Norwegian PV TIS are analysed in section 5.4. Finally, the empirical data and the research questions are discussed in chapter 6.

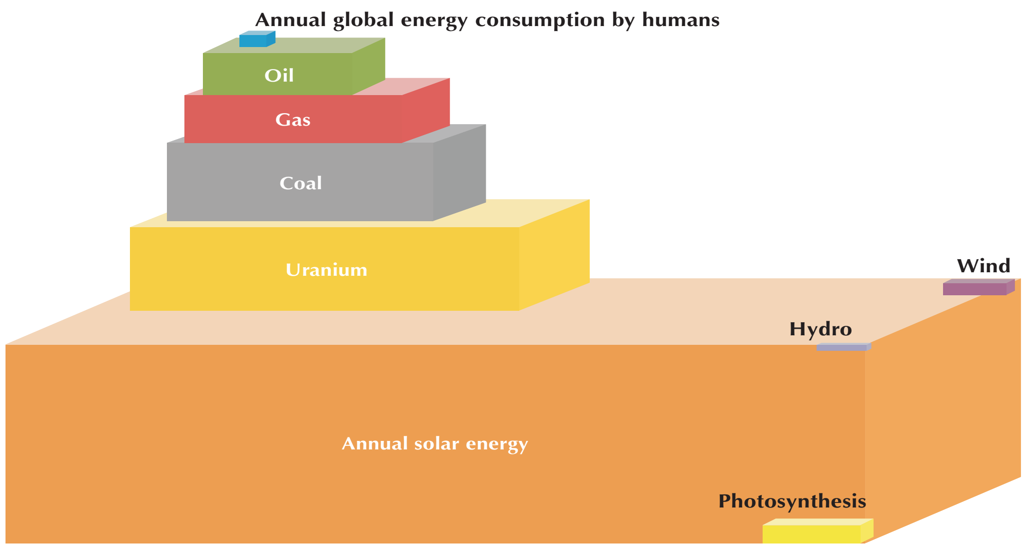
2. BACKGROUND

"The use of the sun has not been opened up because the oil industry does not own the sun"

Ralph Nader, 1943

The International Energy Agency has pointed out that solar energy has more potentials than other RNE sources in terms of availability, quantity and security (IEA, 2011). Understanding these potentials can help reduce the GHG emissions and secure energy consumption that can lead to a sustainable economic development. Similarly, other reports have suggested that PV technologies must play a significant role in the global energy mix in 2050, if global climate change goals are to be achieved in a cost fashionable manner (IEA, 2010). For example, some calculations suggested that Europe's electricity demand could be met if 0,34% of the European land is covered with PV modules (EPIA & Green Peace, 2011). As illustrated in figure 2.1, the annual energy received from the sun exceeds the total estimation of fossil resources. In addition, several findings have suggested that the available solar radiation is more than enough to meet the world's energy demand (EPIA & Green Peace, 2011; IEA, 2011). In fact, the amount of sunlight that strikes the earth in 90 minutes is enough to supply the planet for energy in one year (IEA, 2011). Still, solar energy only represents a small fraction of the global energy mix. Even among renewable sources, direct uses of solar energy are still outperformed by biomass, hydropower and wind (see Figure 2.2).

Figure 2.1: Global Energy Sources

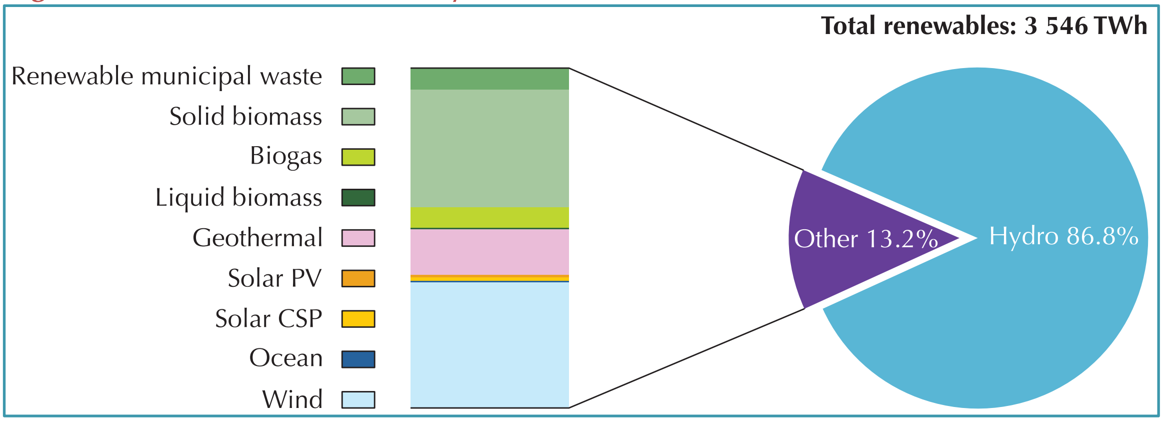


Source: (IEA, 2011)

Key Points:

Solar energy is largest energy resources on earth.

Figure 2.2: Renewable Electricity Generation in 2007



Source: (IEA, 2011)

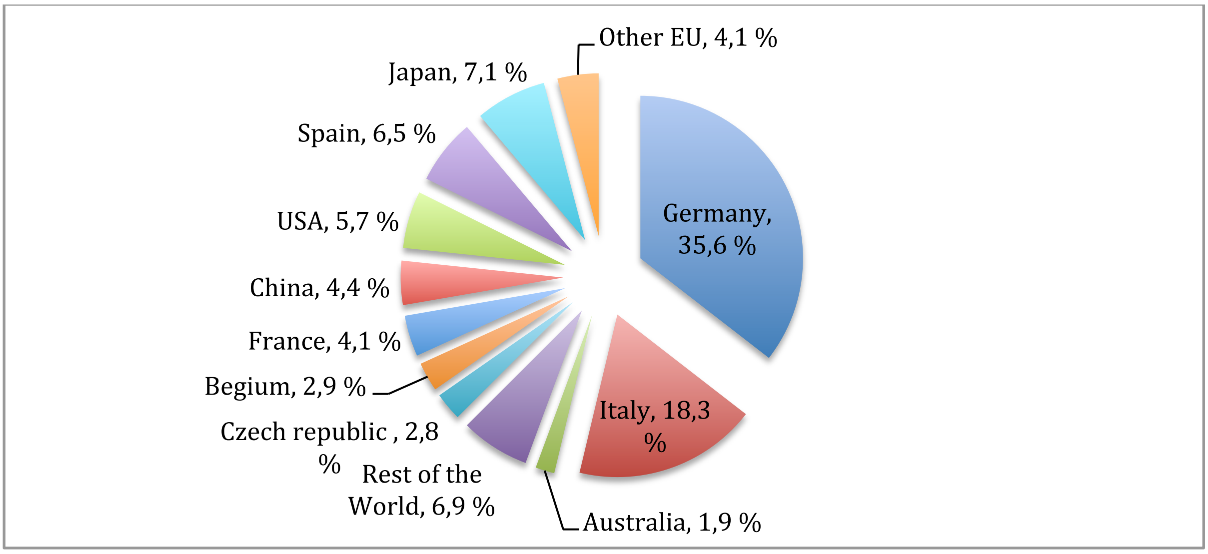
Key Points: *The consumption of solar electricity is small compared to other renewable sources.*

2.1 THE ECONOMICS OF PHOTOVOLTAIC

Solar energy, although amongst the fastest growing renewable energy sources, it is still viewed as inefficient and expensive energy source. These views are rapidly changing, because of the increasing global actions in improving the world's energy security. Several reports and research studies have shown that PV technology has experienced continuous price reduction in recent years, and it is approaching grid parity in the near future (EPIA & Green Peace, 2011; IEA, 2010; IEA, 2011; IRENA, 2012). In fact, the PV market has experienced rapid growth in the last decade with an annual growth rate of 40% (IEA, 2010). This development is guided by cost reduction, technology innovation and production optimization, which has in turn led to economic of scale (IRENA, 2013). Improvement in PV performance ratio as well as policy instruments such as Feed-In-tariffs has also contributed to this development (REN21, 2012). Other contributing factors include the overcapacity in the market and pressure from Chinese producers (IRENA, 2013).

In 2011, the lowest prices available in the market were USD 1.59/W for mono-crystalline PV modules, USD 1.63/W for multicrystalline PV modules, USD 1.52/W for CdTe thin-film modules and USD 1.22/W for amorphous silicon PV modules (IRENA, 2012). Prices continued to fall drastically in 2012. During September and December 2012, the average prices for crystalline silicon PV module from Chinese producers have fallen to USD 0.75/W, while the prices from western manufacturers was at USD 1.1/W. Moreover, the average cost from Chinese producers was at USD 0.75/W (IRENA, 2013). This rapid cost reduction means that PV technologies are entering new areas of competitiveness. In a cost analysis report from 2012, The International Renewable Energy Agency mentioned that continuous reduction in production costs means that PV can reach grid parity between 2012 and 2013 in sunny regions such as USA, Japan and Southern Europe (IRENA, 2012). Essentially, countries are investing in PV technologies as a part of smart energy solutions. For instance, almost 30 GW of new solar PV capacity operated worldwide in 2011, increasing the global total capacity by 74% to almost 70 GW (REN21, 2012). The European Union (EU) was the largest PV market in 2010 and 2011 with installations of 13GW and 17GW respectively (REN21, 2012; EPIA, 2011). As illustrated in Figure 2.3, Germany continues to lead the way in terms of smart policies and political commitments (RNE 21, 2012). The German FITs system has been the main driver of this trend; allowing the PV system to develop and compete with other mature renewable technologies (ibid). The country connected its one-millionth PV system to the grid in late 2011, and continued to lead total installed and operating PV capacity (REN21, 2012). Italy and Germany accounted for around 54% of new operating capacity in 2011 (Figure 2.3). Outside Europe, the largest markets were Japan with 6,5%, USA with 5,7% and China with 4,4% (ibid).

Figure 2.3: Solar PV Operating Capacity, Top 10 Countries, 2011



Source: (REN21, 2012)

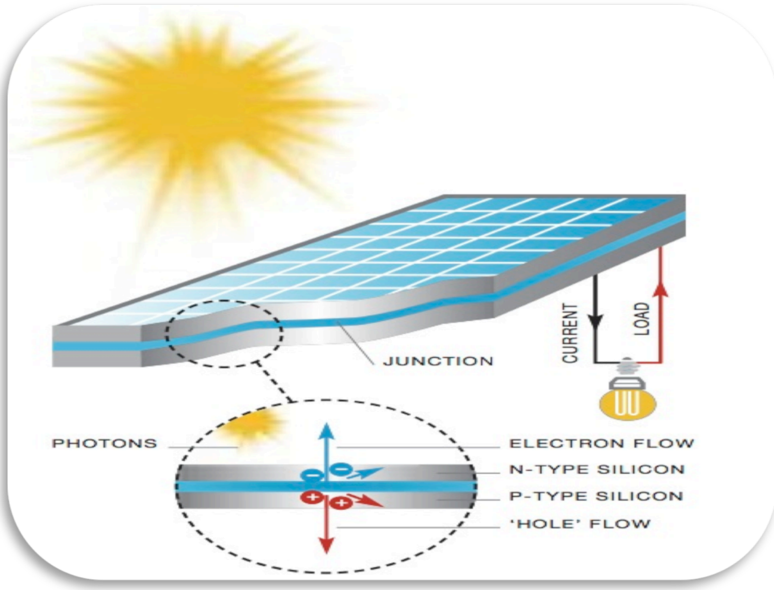
Key Points: *EU was the largest PV market in 2011 due to Germany and Italy, which together accounted for almost 54% of the market.*

2.2 THE PRINCIPLE OF PHOTOVOLTAIC AND PV TECHNOLOGIES

Photovoltaic also referred to as, solar cells is a process of converting sunlight into direct current electricity. This process is called the PV effect. The word photovoltaic is derived from the words *photo* meaning "light" and a *volt,* which is the measurement of electricity (EPIA & Green Peace, 2011). The most common material in PV is silicon, which is a semi conductive material that can absorb and convert sunlight into electricity. When a PV cell is exposed to the sun, it creates an electric field across the layers causing a flow of electricity (ibid). This conversion is caused by the chemical properties that exhibit in silicon. An atom of silicon is consisted of three different layers with 14 electrons. The first shell is consisted of two and eight full electrons. The outer shell is only half full and consists of four electrons. A silicon atom has ways of filling the last shell. In doing so, it shares electrons with four neighbour atoms. This process forms the crystalline structure, which is important for PV cell. Although the crystalline silicon has a PV effect, it is a poor conductor of electricity. This is mainly because the electrons in silicon are not free to circulate.

Since the PV cell needs both negative and positive charges in order to create an electric field, the silicon in a PV cell is purposely manipulated with Phosphorous on one side and Boron on the other side. (EPIA & Green Peace, 2011; European Commission, 2009). This process of impurity is referred to as *doping*. The boron does not have a positive charge, but it has free openings that attract electrons. Doping the silicon with boron creates p-type silicon (p=positive). The phosphorous has a negative character called the *n-type silicon* (n= negative) (EPIA & Green Peace, 2011). As illustrated in Figure 2.4, the n-type is not charged, but its electrons are not held to the atom – they can move within the layer, making it a better conductor than pure silicon (European Commission, 2009).

Figure 2.4: Photovoltaic Effect



Source: (EPIA & Green Peace, 2011)

In order to create an electric field, the free electrons from the n-layer move to fill the openings in p-layer. This point of contact is called the *p-n junction* (EPIA & Green Peace, 2011; European

Commission, 2009). When the PV cell is exposed to the sun, photons of light break apart the electrons in the p-n junction (Figure 2.4). The electrons are drawn to the positive charge of the n-type and kept away by the negative charge in the p-type silicon (EPIA & Green Peace, 2011). If a conducting wire connects both sides, an electric circuit can be formed (EPIA & Green Peace, 2011). The wire creates a path for the electrons to move away from each other (European Commission, 2009). This flow of electrons, illustrated in Figure 2.4, is an electric current that can be used as electricity.

2.2.1 TYPES OF PV TECHNOLOGIES

The PV market is composed of various types of technologies, including silicon-based and thin film solar cells. The commercial and future technologies have been grouped into first, second and third generations (Bagnall & Boreland, 2008). The first generation include crystalline silicon cells (c-Si), the second generation is based in Thin Film technologies (EPIA & Green Peace, 2011) and the third generation includes concentrating PV (CPV), Dye-sensitized solar cells, organic solar cells and other novel and emerging solar cell concepts (IRENA, 2012). Table 2.1 provides an overview of the efficiency level of available commercial PV technologies and their market share. The direction of technological change, in terms of competition between designs is also illustrated in the table, which shows the market share of each technology and efficiencies. Among all the PV technologies, crystalline silicon solar cells are in the lead with 85 to 95%, followed by thin film cells with 10-15% of the market share (IEA, 2010). However, while the efficiencies of the different PV technologies vary on the basis of efficiencies, these differences at less significant at an overall comparison, which takes into account the efficiency in terms of area needed for the technology (IRENA, 2013; EPIA & Green Peace, 2011).

Table 2.1: Overview and Comparison of Commercial PV Technology

Technology	1st Generation PV		2nd Generation					3rd Generation
	Crytalline Silicon (85-90% market share)		***Thin Film*** (10-15% market share)					***CPV*** (under 1% market share)
	Mono	**Multi**	**(a-Si)**	**(CdTe)**	**CI(G)S**	**a-Si/μc-Si**	**Dye s. cells**	**III-V Multi-junction**
Cell Efficiency	16-22%	14-18%	4-8%	10-11%	7-12%	7-9%	2-4%	30-38%
Module Efficiency	13-19%	11-15%						~25%
Area needed per KW (for modules)	~7m²	~8m²	~15m²	~10m²	~10m²	~12m²		

Source: (EPIA & Green Peace, 2011; IEA, 2010)

Key Points:

There are various ranges of PV technologies currently available in the market, and these technologies vary in terms of efficiency and cost.

❖ First Generation PV Technologies: Crystalline Silicon Cells

Currently, the majority of PV cells introduced in the market are *first generation* (1G) wafer based silicon (European Commission, 2009). They have dominated the market since 1950 (Andersson & Jacobsson, 2000). Silicon cells are made of thin slices of wafers, which are sawed out of blocks of silicon. Crystalline silicon cells are categorised into three groups depending on how the Si wafers are made: Mono-crystalline (sc-Si), Polycrystalline (Poly c-Si) or multi-crystalline (mc-Si); and EFG ribbon silicon and silicon sheet-defined film (EFG ribbon-sheet c-Si) (IRENA, 2012). Cells created from a single crystal rod or block composed of multiple crystals are respectively called mono-crystalline or multi-crystalline silicon solar cells (Juel , 2012; Grimsrud, 2012).

The first activity in the value chain of silicon cells is the process of silicon feedstock, which involves the selection of high quality raw material for the production and refining of silicon feedstock (Grimsrud, 2012; Foss, 2012; Juel , 2012). Companies such as REC, FESIL Sunenergy and Elkem Solar are involved in these types of activities. During this process, silicon is purified into solar grade silicon and melted into a block, which is cut into smaller blocks of ingots in the second process of the value chain (Grimsrud, 2012; Kaus, 2012; Foss, 2012). The use of large amount of materials combined with the characterisation (purifying) of the silicon, normally leads to high cost in production (Andersson & Jacobsson, 2000). However, Norwegian players such as Metallkraft AS and Sic Processing AS have developed recycling technologies, which enables producers to avoid kerf losses during the cutting and characterisation processes. The ingots then goes through a process of crystallisation and wafering, which involves producing materials that consist of large, or one silicon crystal (Foss, 2012; Grimsrud, 2012). Thereafter, the block (for multicrystalline cells) or cylindrical (for mono-crystalline cells) crystals are sliced in thin wafers[1] that can be processed to solar cells. (Kaus, 2012; Foss, 2012; Grimsrud, 2012) NorSun, Elkem Solar and REC are involved in the production of wafer. The wafers are then fitted with grid contacts, put into aluminium frames and assembled into solar panels (Foss, 2012; Grimsrud, 2012). REC is the only Norwegian producer involved in all activities from the processing of raw material to modules (Foss, 2012).

[1] The wafers are chemically treated to increase the energy efficiency
[2] CdTe PV cells are also one of the most developed thin film cells.

❖ **Second Generation PV Technologies: Thin Film Solar Cells**

In order to compete with cost, the *second-generation* technologies, thin film solar cells have been introduced in the market. Thin films currently account for 10% to 15% of global PV module sales (IEA, 2010). These cells are single-junction devices, which use less material while maintaining efficiency. Wafer-based silicon solar cells are approximately 200 μm thick while thin-film solar cells are approximately 1-2 μm thick (European Commission, 2009).

Although thin film cells are less efficient than silicon solar cells, there are fewer manufacturing activities in their value chain, composing of five common manufacturing processes (See Figure 2.5). During the first process, a large sheet of substrate of glass is produced (EPIA & Green Peace, 2011). The substrate is then covered with a transparent conducting layer (CTO). In the third step, a semiconducting material is deposited onto the substrate. A metallic contact is applied on the back of the layer through a laser scribing process (EPIA & Green Peace, 2011; IRENA, 2012). Finally, the module is enclosed in a glass, polymer or metal (EPIA & Green Peace, 2011). In summary, thin Film cells are assembled by depositing thin layers of photosensitive material on to a glass, polymer or metal (EPIA & Green Peace, 2011; IRENA, 2012). Once the material is attached, it goes through a laser cutting process into several cells (EPIA & Green Peace, 2011). Due to its flexibility, modules made of thin film cells can be easily integrated into building components (IRENA, 2012).

Figure 2.5: The Value Chain of Thin Film Solar Cells

Source: (EPIA & Green Peace, 2011)

Key Points:

The manufacturing process of thin film solar cells is less complex than the one of silicon based solar cells.

There are three different types of thin films: the amorphous silicon cells (a-Si), which has low efficiency and limited lifetime (approximately 10-15 years, cadmium telluride cells (CdTe) and copper-indium-Selenide (CIS) and Copper-idium-gallium-diselenide cells (CIGS) (Bagnall & Boreland, 2008). Amorphous silicon solar cells, although the most developed thin-film solar cells[2], suffer from a significant reduction in power output over time, because the sun degrades their performance (IRENA,

[2] CdTe PV cells are also one of the most developed thin film cells.

2012). CdTe cells have achieved the highest production level than all other thin film technology (IEA, 2010) in terms of production and efficiency (IRENA, 2012). This combination of low production cost and high efficiency makes them the most economical thin film technology (EPIA & Green Peace, 2011), and allowing them to dominate the thin film technologies in terms of market share (IEA, 2010). CIS and CIGS cells offer the highest efficiencies of all thin film technologies (EPIA & Green Peace, 2011; IRENA, 2012). Their production process is nevertheless more complex than other cells, which normally increase the production cost (EPIA & Green Peace, 2011). One of the advantages of thin film technology as compared to crystalline silicon cells is their low consumption of raw material (European Commission, 2009), their high automation and production efficiency (IEA, 2010) as well as their requirement of less active semiconducting material in absorbing sunlight (IRENA, 2012; European Commission, 2009). Consequently, economic of scale can be easily achieved in large production scale.

❖ Third Generation PV Technologies

The future goal in PV market is for the *third generation* solar cells to achieve the combination economic of scale, low cost productions and high efficiency solar cells. Many players are currently undertaking wide range of R&D activities involving emerging technologies, including concentrating photovoltaic (CPV), organic solar cells (IEA, 2010) and novel concepts based on nanotechnologies (IRENA, 2012). CPV utilises lenses or mirror to concentrate direct solar radiation onto highly efficient (ibid). CPV cells are however expensive multi-junction solar cells (EPIA & Green Peace, 2011). In addition, the lenses need to be oriented toward the sun in order to achieve effectiveness (IRENA, 2012). This means that this type of technology has the potential of achieving full efficiency in very sunny areas such as North and West Africa. Other third generation technologies include Dye-sensitized solar cells, which use photo-electrochemical solar cells. These cells use low cost materials and they are simple to manufacture (IRENA, 2012). Organic solar cell is another inexpensive novel technology, emerging as a niche technology (IEA, 2010; EPIA & Green Peace, 2011). Their production is a combination of high-speed and low temperature roll-to-roll manufacturing processes and printing technologies (IRENA, 2012). Other novel concepts include solar cells based on Nano technology. For example, the Norwegian player EnSol As is developing a thin film PV cell based on nanocrystal technology (Ensol AS, 2012).

2.3 THE ENERGY SITUATION IN NORWAY

As the world's third largest exporter of oil and gas (IEA, 2006) and the producer of 3,4% of the world's hydroelectricity (IEA, 2012, p. 19), Norway has a unique energy situation. In fact, hydropower accounted for around 99% of its total electricity production (SSB, 2012). In addition, around 50% of the end consumption of energy is electricity (ibid). Moreover, Norway is a nation of vast renewable resources; an advantage for businesses and Norwegian industries in terms of access to renewable sources in the production process. At the same time, as one of the largest producers of oil and gas, Norway does not only contribute to the consumption behaviour and energy security of other countries, but it also contributes to the world's emissions. The country's GHG are about 12 tons of CO2 equivalents per capita, and are among the highest in the world (Klimakur 2020, 2010). In addition, Norwegian energy consumption per capita is above the average in OECD countries (ibid). This means that Norway has a certain responsibilities and obligations in contributing to the reduction of the world's GHG emissions. Therefore, the Norwegian energy system needs to be viewed and managed in a global context.

2.3.1 PHOTOVOLTAIC IN NORWAY

Norway has a competitive and extensive PV manufacturing industry through players such as NorSun, Elkem Solar and REC. The main activities of these players involve the production of crystalline silicon solar cells. Focusing on international market is not surprising given the fact that most of the country's electricity consumption is based on hydropower. Although energy produced from solar panels have reached grid parity in some regions (IRENA, 2013), solar energy cannot yet compete with other renewables in Norway. Approximately 420 kW of PV power was installed during 2011, making the total installed capacity in 2011 approximately 9,5 MWp (Bugge, 2012). The main market for PV continues to be related to off-grid applications in the leisure market for recreational use in cabins and leisure boats as well as in the professional market for lighthouses along the coast and telecommunication systems (SINTEF, KanEnergi, 2011; Bugge, 2012). In regards to coastal navigation infrastructure, there were approximately 2890 plants in operation with a total capacity of 315 kWp (SINTEF, KanEnergi, 2011). Still, the leisure segment accounts for 80-90% of the Norwegian market (Bugge, 2012). In addition, applications of stand-alone PV for telecommunication stations and hybrid utility systems have also grown during recent years (ibid).

3. METHODOLOGY

"You know my method. It is founded upon the observation of trifles" **Arthur Conan Doyle**

"I want to understand the world from your point of view. I want to know what you know in the way you know it. I want to understand the meaning of your experience, to walk in your shoes, to feel things as you feel them, to explain things as you explain them" **James P. Spradley**

In a research study, a researcher must define the structure and methods of data collection suitable for the purpose of the enquiry. This chapter illustrates the relevant strategic choices taken in regards to research design, data collection and analysis. It gives an overview of the research strategy, design and method employed in this study. It also discusses the quality as well as the ethical dilemmas.

3.1 RESEARCH STRATEGY & DESIGN

Since the purpose of the study is to understand innovations processes and the dynamics of change in the Norwegian PV TIS, a qualitative case study method has been employed in order to explore endogenous aspects of technological change. The research strategy is based on qualitative single case study rather than a quantitative approach, since the study does not intend to make any statistical generalisation.

3.1.1 STRATEGY FOR A QUALITATIVE RESEARCH

Choosing a research strategy is a way of linking the research questions and objective to a specific method. In the word of Ragin and Amoroso (2011, p. 36): "Because social research has multiple goals, a variety of different research strategies has evolved to accommodate those goals". In other words, research strategies set the foundation of how data should be collected and analysed (Ragin & Amoroso , 2011, p. 51). For instance, a qualitative research would be the appropriate strategy when the research seeks to understand the "why" and "how" of human behaviour or phenomenon with the goal of giving a voice to a marginal group, interpreting cultural and historical phenomenon or advancing a theory (Ragin & Amoroso , 2011, pp. 51, 112-116). As such, qualitative research can be regarded as strategy involving certain methods of data collection. These methods may include interviews, observations, participatory observations, documents analysis, analysis of audio recording that makes it possible to explore, examine and describe people in their natural environments (Orb, et al., 2000).

Since the study seeks to understand endogenous factors, it is convenient to use qualitative research, rather than quantitative research. This is because qualitative research differs from quantitative research, in that the latter aims to present objective truths in the form of statistical results base on several samples, standardised measures and linear process; while the former seeks to understand human experiences by examining few units in depth (Riege, 2003; Ragin & Amoroso , 2011). As such, qualitative methods seem to be more flexible, as it makes possible to work with various phases of the research process.

3.1.2 DESIGNING FOR A CASE STUDY

Having set the strategy for the study, this section looks at the design employed in structuring this thesis. Yin describes the research design "as a logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions" (Yin, 2009, p.26). During the process of the literature review, the author of this thesis have discovered that the Norwegian PV TIS emerged as a result of knowledge and competence acquired from the metallurgical, aluminium and process industries. Since the study intended to explain the evolutionary process and the emergence of the system, the fundamental objective of the inquiry was to uncover the historical lessons from these industries. In that sense, one may ask whether the case study as design is appropriate for this study, and why not simply employ history methods as a design choice. It is worth noting that the case study design has commonality with historiography, and "relies on many of the same techniques as a history" (Yin, 2009, p. 11). However, case study employs two more sources of evidence that are not as commonly used in historical method; namely "direct observation of the event being studied" and interviews with people involved in the events (ibid). In addition, with the case study as method, a researcher is free to employ multiple sources of evidence such as interviews, document analysis, direct observations and artefacts that may not be available in a historical study (Yin, 2009, p. 11). Likewise, since the purpose is to understand an emerging technology, the dynamics of its innovation processes and structures as well as the inducement and blocking mechanisms influencing its development, drawing on historical sources, statistics, archives or survey would not suffice for capturing historical and current dynamics of the Norwegian PV TIS.

Yin (2009, p.18) has provided a twofold definition of case studies, the first part stars with the scope of a case study, and the second part deals with technical issues, and how a case study can be conducted. In regards to the scope, a case study is "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2009, p. 18). In another word, a case study can be used when the purpose is to understand a contemporary phenomenon in their natural context, but such understanding requires the perspectives of the participants involved in the phenomenon. Similarly, understanding a technological innovation system is a complex phenomenon, which requires in depth analysis of the relationships and interactions between actors, institutions and networks. Since a distinction between phenomenon and context are not always visible in real life situations, the second definition deals with technical characteristics concerning strategies of data collection and analysis. As such, "the case study inquiry:

- copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
- relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
- benefits from the prior development of theoretical propositions to guide data collection and analysis" (ibid.).

These two definitions show that the case study design covers all the processes of a scientific study. In addition, the study seeks to understand the dynamics and the emergence of a phenomenon – understanding the *"how"* of innovation processes and institutional changes. This should be a great starting point, since case studies are preferred when the questions "how" and "why" will be investigated, and when the researcher has little control over events (Yin, 2009, pp. 4-8). The TIS framework does not only serve as a theoretical foundation in which this thesis is built on, it also provides steps and directions of how to best study a novel industry or technology. Another important point is that the framework deals with all the essential characteristics concerning the evolution of innovation systems by using perspectives from several disciplines of evolutionary economics.

3.2 METHODS OF DATA COLLECTION

The study was guided by the methods based on Bergek et al. (2008) on how to measure the different functions of TIS. Yin (2009) argued that the method of data collection would influence the interaction between the research question and empirical data. Since the study is based on qualitative research strategy, multiple sources of evidence have been used in order to understand the complexity of the Norwegian PV TIS. These sources include document analysis of policies and white papers, interviews and participatory observations.

3.2.1 REVIEW OF LITERATURE

One essential phase of data collection process consists of identifying literature that is relevant to examine the research question (refer to chapter 4 for more details). The theoretical foundation of the thesis consists of literature on evolutionary economics and innovations systems (IS), with special emphasis on technological innovation system. Yin (2009, p.40) mentions that a case study design departs with a theoretical review (analysis), whether the study is explanatory, descriptive or exploratory

(Yin, 2009, p. 40). The literature review was vital in the methodological process, which helped gain academic insights on evolutionary economics and the essence of innovation and technology. The TIS framework is employed here as a theory to increase our understandings of the PV technology in Norway. The framework is suitable for this type of research, because it explores the boundary of a novel technology, its structures and dynamics of how a technology emerges and develops. Evidently, during the process of the literature review, the research questions were clarified in ways that are relevant for the purpose of the inquiry. In addition, more insights on *Evolutionary Economics* and *Innovation Systems* made it appropriate in placing the thesis in the context of TIS, and hence established a relationship between the research questions and *Technological Innovation Systems*. Yin (2009, p.40) also mentions "the use of theory in doing case studies, is an immense aid in defining the appropriate research design and data collection". The methods proposed by Bergek and colleagues (2008b) are employed in order to understand the development of the PV system. This method laid the foundation for the research design and strategy.

3.2.2 PARTICIPATORY OBSERVATIONS

While reviewing the literature, the author of the thesis have participated in two conferences in 2012, which brought together organisations, research and industry players. The first conference; the European Solar Days was arranged by The Norwegian Solar Energy Society (NSES), and held in May 2012 in University of Oslo with the theme "Solar Energy in Practice" (Refer to appendix 4 for conference agenda). The second conference was arranged by Teknova and UiA and held in Kristiansand on 9th May 2012. The theme of the conference was "Survival and innovation in the solar industry, in face of increased global competition and economic crisis" (refer to appendix 5 for program".

This type of method of data collection can be viewed as a participatory observation. Although Participant-Observation activities make it possible to gain access to events and groups that are otherwise inaccessible, it can also create problems of unbiased data or information (Yin, 2009, pp. 111-113). This is because the participant role may require too much attention relative to the observer role. As such, the participant-observer may have insufficient time to raise questions about the events from different perspectives. In this matter, a researcher should consider the trade-offs between opportunities and problems before undertaking a participant-observer study. However, these conferences have not only allowed the author of the thesis to gain in depth understanding of the PV technology and industry, but they also presented the opportunity to interact with actors and industry experts, and in doing so, map the relevant informants for the interview stage. Notes were taken during both conferences. All the presentations from both conferences were also recorded, and transferred to readable audio files.

3.2.3 INTERVIEWS

Mapping the opinions of key actors is an essential method for data collection when analysing the dynamic of a TIS. As such, informants that were perceived relevant were companies with upstream, midstream and downstream activities, universities involved with PV activities, research institutes, organisations and governmental agencies. The main purpose of the interviews was to map the perceptions, attitudes, motivations of these actors, the innovation and market strategies of relevant companies as well as institutional frameworks in order to understand the overall performance of the system. Interview candidates were identified from those the author met during the conferences and from the lists of participants from the conferences. Additionally, the snowball effect was employed in order to establish contact with all relevant stakeholders.

Establishing contact with the informants was easier than anticipated, however several challenges were encountered during the interview process. For instance, one of the challenges of qualitative interviews is that interview subjects are either too small or too large (Kvale & Brinkmann, 2009; Yin, 2009). At the initial stage of the interview process, 25 actors were identified as relevant candidates for interview. On one hand, interviewing too many people meant more time would be used in transcribing data. On the other hand, it would be difficult to produce enough material if the amount of informants is too small. After all, the most important sources of evidence in the qualitative case study are the interviews (Yin, 2009, p. 106). Eventually, a decision was taken to interview as many informants needed for producing enough knowledge necessary for the purpose of the study. In the word of Kvale: "Interview as many subjects necessary to find out what you need to know" (Kvale, 2006). Essentially, 18 informants were interviewed; ten of the informants were men and eight were women. Although 18 informants are listed in appendix 1, Ole Grimsrud and Alf Bjørseth were interviewed together, because of time restrictions. This means that 17 interviews were conducted, recorded and transcribed.

Qualitative interviews provide us with an understanding of the world of the subjects' point of view (Kvale, 2006, p. 481), because knowledge is produced knowledge through the interaction between the interviewer and the interviewee (Kvale & Brinkmann, 2009, p. 117). Likewise, during the process of conducting the interviews, the purpose was to provide conversational environment hat served the purpose of the thesis, in a way that allowed the author to follow up on the logic and answers from the interviewees without undermining the integrity of the study. For instance, in explaining the process of an interview, Yin (2009, p. 106) suggested that the interviewer should "follow a line of inquiry" that reflect the purpose of the case study, while at the same time asking unbiased questions that "serves the needs of the line of inquiry". In doing so, all interviews were semi-structured; containing a list of questions covering the seven innovations processes outlined in the literature chapter (refer to section 4.5.3). These questions served as an interview guide, indicating the topics and their sequence (Kvale, 129), with detailed worded questions. The guide illustrated in Appendix 3, served as a guide, and the structure of questions were altered, modified, revised several times and adapted to each interviewee. Structuring the questions in accordance to the purpose of the study, and in the realm of the theoretical framework simplified the organisation of data and the analysis. Additionally, using semi-structure interviews simplified the process of following up questions and new themes introduced by the interviewees. This was an important way of clarifying the position of the informants as well as discovering new themes or challenges that would otherwise remain uncovered.

Each interviews lasted between 45 and 90 minutes. All the informants received information about the study beforehand. Still, all interviews started with the author stating the purpose of the study, and the plan for using the information gathered. All the interviews were conducted in Norwegian except from one, because the informants spoke Swedish.

3.2.4 DOCUMENTS

Systematic search for relevant documents is an essential process in collecting data, since documents play an explicit role in data collection, (Yin, 2009, pp. 103-105). The document reviewed in the thesis included government strategic documents, industry's reports, policy documents, reports from institutions and organisations, scientific articles, research reports and articles from online newspapers. In explaining the role of document review in case studies, Yin (ibid) mentioned that the use of document is to corroborate and increase the evidence from other sources. Therefore, the purposes of reviewing these documents are three folded.

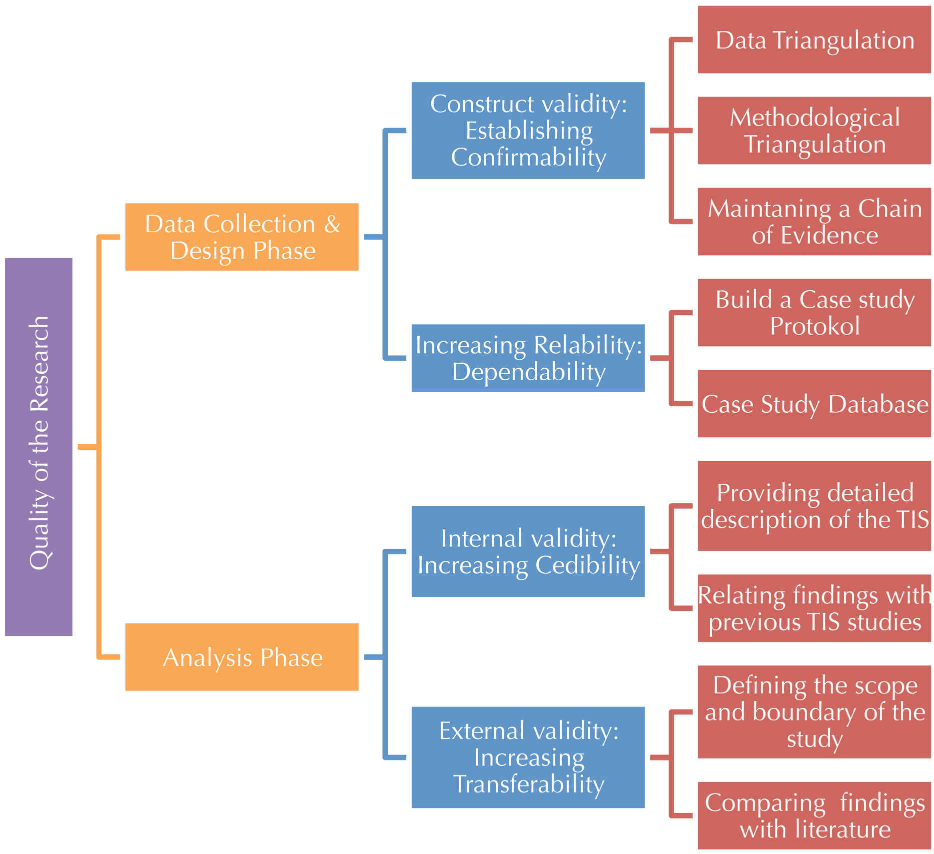
First, before the process of data collections, industry documents and articles from online new papers were used as sources of information in increasing the author's knowledge of PV industry and innovation system in Norway. They helped assessed the challenges and opportunities of the PV industry, hereby allowing the author to follow the conversations during the conferences, and to ask relevant questions. Second, by reviewing industry reports and policy papers, the author of this thesis was able to map structural components of the system such as relevant companies, organisations, industry associations (actors), networks and institutional frameworks such as law, regulations and policies. This process helped understand not only the structural elements of the system, but also the overall changes in the industry. For instance, news articles online were useful in retrieving both historical and current situations of the industry. Understanding these elements helped identify relevant questions for the interview process. Third, the documents reviewed served as ways of verifying evidence gathered from interviews and the conferences and vice versa. In this way, the author could pursue "problem by inquiring further into the topic" (Yin, 2009, p. 103) if evidence from the documents reviewed contradicted with data from fieldwork. For instance, the names of the partner companies that came in interviews were verified through the review of industry and research papers.

3.3 THE QUALITY OF THE RESEARCH

As mentioned earlier, qualitative research is subjective as opposed to quantitative approach, which aims at testing hypothesis, making predictions or discovering causes and effects. Similarly, Riege (2003) mentioned that case studies are based on the realistic method, in a way that the main purpose is to uncover realities, and understand the meaning of experiences rather than verifying predetermined hypotheses. As such, the belief system of the researcher could influence the inquiry, and no objective or value-neutral knowledge could be produced during such interactions (Kvale & Brinkmann, 2009; Riege, 2003; Yin, 2009).

To what extent is the researcher's voice and interpretations privileged relative to those being studied? As the researcher observes, interprets and analyses social life, he or she makes decisions with respect to what is included and omitted. What or who gets attention and what (who) is ignored in the final representation (Kvale, 2006; Kvale & Brinkmann, 2009; Orb, et al., 2000). As such, issues involving dependability, confirmability, reliability and credibility demand attention in assuring the quality and trustworthiness of a qualitative case study (Yin, 2009, p. 40; Riege, 2003). In dealing with these issues, scholars have suggested four tests, each with its own tactics (see figure 3.1). Tests involving construct validity, reliability, internal and external validity for quantitative research approaches while tests involving credibility, transferability, dependability and confirmability are designed for qualitative approaches in order to enhance the quality of case study research (Riege, 2003; Yin, 2009, pp. 67-162). As illustrated in Figure 3.1, four designs tests that have been applied in order improve the quality of this study.

Figure 3.1 Tactics for Assuring Quality of the Thesis



3.3.1 CONSTRUCT VALIDITY & CONFIRMABILITY

Construct validity deals with the confirmability, which refers to the objectivity of the research (Riege, 2003). Since, qualitative case study is subjective, it is important to refrain from subjective decisions during the processes of research design and data collection (ibid). These tests enable the researcher to construct validity, (Yin, 2009, p. 41; Riege, 2003). Yin recognises the importance of applying "correct operational measures for the concepts being studied" (Yin, 2009, p. 41).

Three techniques have been employed in order to construct validity. The first two tactics involve triangulation[3]. Data triangulation and methodological triangulation have been employed during the data collection phase in order to construct validity and increase the objectivity in this thesis. The first test, data triangulation involves using multiple sources of evidence in the interview phase. In doing so, different groups of actors including universities, organisations and networks, research institutes and industry players from all part of the value chain (see appendix 1). The use of multiple sources of evidence makes it possible to develop converging lines of inquiry; processes referred to as triangulation (Yin, 2009, pp. 115-116).

[3] Yin (2009, 116) suggested four types of triangulation strategies: data triangulation, investigator triangulation, theory triangulation and methodological triangulation.

The second tactic, methodological triangulation involves using multiple methods to collect data during the design phase (and data collection phase). In this study, three methods including interviews, documents review and participant observations have been used in order to collect data. The intention is to decrease the biases that come from any single method of data collection. These two tests address the problems of objectivity, because studying the same phenomenon from multiple sources provides multiple measures of the same problem (ibid). The third tactic employed for constructing validity involves the establishment a chain of evidence in the data collection phase (Riege, 2003; Yin, 2009, pp. 122-124). In doing so, all the interviews were recorded and transcribed using a program called HyperTRANSCRIBE. The presentations from all the conferences were also recorded. In addition, notes were taken during all interviews and conferences, which allowed the author of the thesis to crosscheck the sources of evidence, between the notes, the transcripts and the audios. As a result, the findings from the different sources were corroborated in such ways that the weaknesses from one data were compensated by the strengths of other data, thereby increasing the validity and objectivity of the thesis.

3.3.1 RELIABILITY AND DEPENDABILITY

The tests of reliability in quantitative study and those involving dependability in qualitative case study deal with the same problems (Riege, 2003). The purpose of these tests is to indicate whether the procedures employed in the research design are consistent, in a manner that, other researchers can achieve the same findings when the proceeding operations are repeated (Riege, 2003; Yin, 2009, p. 45). Two tests helped increase the dependability of this study.

First, a case study protocol helped to ensure that the process of the research is rational, traceable and well documented. In doing so, all interviews and presentations from the conferences were recorded and transferred into readable audio formats. In addition, all interviews were transcribed and saved. Moreover, notes were taking during all interviews and conferences. The transcriptions, notes and audio were all used during the analysis process, enabling the writer of the thesis to corroborate between data gathered from all methods of data collections. Second, a case study database was established during the phase of data collection in order to make the analysis more transparent. The audio recordings from the two conferences, the interview transcripts as well as the industry papers, policy and white papers were organised using research software called NVivo. With the program, the findings were organised through coding, nodes and categories, allowing the writer to conduct the analysis in a more systematic manner. All in all, the data gathered were coded in accordance to the seven functions of the innovation processes as well as the structural components outlined in the literature chapter. Since, each function has several characteristics, the data were coded in according to the characteristics and organised hierarchically under the function. For instance, the following characteristics were structured under the functions "influence of the search of the directions": The articulation of demand, incentives, regulatory pressures, changes in landscape, belief in growth potential etc. These tactics have helped increase the reliability of the study.

3.3.2 INTERNAL VALIDITY & CREDIBILITY

Internal validity deals with the credibility of the study. In quantitative research, establishing cause and relationships have been the traditional ways of constructing internal validity (Riege, 2003). However, in qualitative case study, constructing internal validity involves establishing credibility during the analysis process (Yin, 2009; Riege, 2003). Two tactics have been employed in the analysis phase.

Frist, a great attempt has been made in providing a detailed description of the Norwegian PV TIS, while at the same time analysing factors influencing innovation processes during the different phase of the system. The intention is to convey the dynamic of the system as well as the contexts surrounding it. As such, the analysis section is structured to illustrate innovation functions and structures with real qualitative episodes gathered during the data collection phase. This enables the reader to assess how far the defined functions and structures embrace the actual conditions of the system. The second tactic involves relating the findings of the thesis with exiting TIS studies in order evaluate the credibility of the study. In doing so, findings from other TIS studies were used to assess the degree to which the dynamics of the Norwegian PV TIS are consistent with other TIS from Germany, Netherlands and Sweden. Each function has been compared to TIS in the aforementioned countries. Finally, findings are supported by evidence from the data collected.

3.3.3 EXTERNAL VALIDITY & TRANSFERABILITY

External validity is similar to transferability, which deals with the generalizability of the study (Riege, 2003; Yin, 2009, p. 43). Constructing external validity in quantitative research is more common, especially when surveys are used with the purpose of making statistical generalisation. Although this thesis does not attempt to make any statistical generalisations, it contains an analytical generalisation, to the extent that, the empirical case develops a general approach to technological innovation system. As such, two tactics have been employed during the phase of data analysis, so that external validity could be constructed. First, the scope and boundary of the study has been clearly defined. The analysis of the empirical data is reflective so that the interpretations of the findings remain within the scope of the study. Second, several attempts have been made in comparing the findings with the literature during the analysis phase. This was done so that literature contributions could be clearly outlined within the scope of the study.

3.4 ETHICAL REFLECTIONS AND LIMITATIONS

Kvale (2006) points out that qualitative interviews are often regarded as a democratic emancipating form of social research, but the research process can create tensions between the aim of the research to make generalisation for the good of others and the rights of informants to maintain privacy (Orb, et al., 2000). Qualitative research is saturated with moral and ethical issues, because of the complexities of the knowledge produced in the social interaction of interviewer and interviewee. As such, one needs to understand the trade-offs between ethics and power in a research process (Orb, et al., 2000; Ragin & Amoroso , 2011). One way of dealing with this problem is to make the power play of this interaction transparent by presenting the methods of an investigation, so that readers may ascertain the potential effects of the power play on the knowledge reported (Kvale, 2006). This has been done in the previous selection, by employing several tactics so that the trustworthiness of the study is increased.

In addition, the utmost care was taken during the phases of interview and analysis in order to evaluate the concerns of power dynamics between the interviewer and the interviewees. First, an information and consent form (in appendix 2) signed between all the interviewees and the writer of this thesis, ensured that each informant was informed with the purpose of the study, and that participation in the research was voluntary. This form formalised the relationship between the interviewer and the interviewees, and obliged the author of this thesis to comply with the ethical considerations stated in the form. Additionally, it helped maintain the integrity of the informants during the interview and afterwards, during the phase of analysis. For instance, the audio recording was turned off during an interview, because the informant provided sensitive information, she did not wish to include in the study. Essentially, the information was left out of the data analysis. Second, in addition to the formal information and consent forms, all informants consented for the quotes that were used in this thesis. Some of the informants made minor changes to the quotes. These tactics have helped balanced the power dynamic between the researcher and the interviewees.

4. THEORETICAL AND ANALYTICAL FRAMEWORK

"Any knowledge that doesn't lead to new questions quickly dies out: It fails to maintain the temperature required for sustaining life" **Wislawa Szymborska**

The Mecca of the economist lies in the economy of biology" **Alfred Marshall, 1948**

The overall objective of this thesis is to understand the development and the emergence of the Norwegian PV TIS. The process through which a technological innovation system emerges involves the creation, development and diffusion of knowledge (Edquist & Johnson , 1997). This process is characterised by innovation and learning processes, institutional changes, demands and interactions between users and producers of the technology (Lundvall, 1985). Therefore, the development of new technology occurs over time, and are influenced by both structural elements and innovation processes (Lundvall, 1985; Edquist , 1997; Bergek, et al., 2008a).

This section presents the theoretical concepts that are deployed in this enquiry. First, the mechanisms of evolutionary economics are reviewed, and the different theoretical approaches of innovation systems (IS) are outlined. Second, these approaches are narrowed down to Technological Innovation System (TIS), which is the theoretical approach deployed in this thesis. TIS is assessed in order to understand the dynamics, structures and processes of technological changes. This delimitation is helpful in explaining the backgrounds of innovation literature to readers that are not familiar to evolutionary economics and IS. The theoretical analysis departs from evolutionary economics and the literature of IS, because these backgrounds are the essence of this inquiry, and without them, the TIS literature cannot alone provide the necessary information for readers that may not be familiar with the IS literature. Although the acceleration and dynamics of technological change and innovation can be studied from different perspectives (technological transition, national Innovation system, Sectoral Innovation System, Regional systems so on and forth), the photovoltaic is an emerging technology, and TIS approach can provide a better understanding of the dynamics of the structural components and innovation processes.

4.1 THE EVOLUTION OF TECHNOLOGICAL CHANGE

The emergence of novel technology can be studied from different perspectives. For example, the neoclassical economists emphasise on price as the determinant of technology choice (Jacobsson & Johnson, 2000). For instance, scholars such as Adam Smith, Solow and Karl Marx treated technological change as exogenous factors (Verspagen, 2005) with the assumptions that firms operate with perfect information (Carlsson & Stankiewicz, 1991) in a perfect competitive environment. In another word, the economy is as an anticipated change. This is worth mentioning, since neoclassical economic theories are not suitable for analysing the innovation processes underpinning the technological changes that are central for this thesis.

Evolutionary economics is however, suitable for this enquiry, because it focuses on the process of economic changes by analysing endogenous forces and qualitative changes (Clark & Juma, 1988). For evolutionary economists, the economic system is made of knowledge, and knowledge is a continuous process of change, in which firms operate in different markets with imperfect knowledge and different strategies (Carlsson & Stankiewicz, 1991). The development and diffusion of new knowledge is thus both individual and collective act (ibid). Evolutionary economics[4] is therefore an analysis of knowledge development, and innovation and technological change are essential ingredients in understanding the complexity of such development. For instance, when analysing the Japanese economic change, Freeman[5] concluded that regulations, government R&D together with educational and political system, contributed to the Japanese economic development (Freeman, 1987). He defined these components as "The Innovation System", which is "the network of institutions in the public and private sectors, whose activities and interactions initiate, import, and diffuse new technologies" (Freeman, 1987)[6]. Freeman's notion of the IS approach viewed innovation as an interactive process of individual and collective activities, which involves learning, diffusion and development of knowledge. This means that the emergence of novel technologies involves complex processes of searching, learning and selection among different opportunities (Edquist , 1997). As such, the IS approach is analytical construct with the purpose of analysing and understanding the complexities of these processes. These factors are relevant in understanding the emergence and development of the Norwegian PV TIS.

4.2 VARIOUS APPROACHES OF IS

Since the seminal contributions from Freeman (1987), several approaches of IS have been developed. Some scholars have focused on the country as the unit of analysis (National Innovation System), in which

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[4] The Evolutionary economics emerged as a critical response to neoclassical economics. The official birth of evolutionary economics starts in 1982 in Nelson and Winter's book "*An Evolutionary Theory of Economic change*". Nelson and Winter stressed on the role of firm and organisational behaviour in economic development (Saviotti, 1997).

[5] Freeman was the first to introduced the concept of "innovation system" (Edquist , 2005), when he analysed institutional factors within the Japanese economic development.

[6] The combinations of institutional and evolutionary theories have led to the Innovation System approach (Hekkert , et al., 2007). The first definition of IS emerged from the book of Freeman in 1987 (Edquist , 2005).

innovation is defined as the force of institutional changes (Edquist & Hommen, 2008; Freeman , 1982; Edquist , 1997; Lundvall, 1992). In other words, the National Innovation System (NIS) involves learning through social interactions, institutional structures and routines, all of which influence the diffusion of innovation within the national system. Lundvall (1992) noted that NIS involves "elements and relationships, which interact in the productions, diffusion and use of new economical useful knowledge" (Lundvall, 1992, p. 2). Nelson (1993) stressed on the importance of interactions between institutional frameworks and productions mechanisms in economic change and growth. Edquist provided a general definition of IS to include "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion, and use of innovations" (Edquist , 1997, p. 14).

The NIS framework[7] is not suitable in analysing the dynamic of a specific technology, because it measures and evaluates the innovative activities at the national level. It links a nation' s innovation activities with its economic performance[8], and explains the elements and relationships that lead to the development and diffusion of knowledge at the national level. The NIS framework is not suitable for the purpose of this study, because it is static, and focuses more on the structural components within a country. TIS is however, more dynamic and process oriented. Since new technology takes time to develop, TIS is a great framework for analysing the blocking and inducement mechanisms of such development. Although, NIS is not suitable for this enquiry, it is worth noting that it analyses the national boundaries, regulations and policies, which influence the innovation activities, and these institutional and production structures influence the decision- making of individual firms (Lundvall, 1985; Lundvall, 1985; Edquist , 2005; Nelson , 1993; Edquist , 1997; Lundvall, 1985; Lundvall, 1985; Lundvall, 1985; Lundvall, 1985). Consequently, the national system influences the dynamic of innovation processes in novel technology. For instance, when analysing innovation activities in the Norwegian PV TIS, Hanson (2008) discovered that forces within the NIS supported the institutional changes in the PV system, which in turn helped foster the creation of new knowledge.

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[7] The framework is especially popular in comparing economic and innovation performances amongst OECD and European countries. Through manuals such as Oslo manual and the Community Innovation Survey (CIS), OEDC analyses the link between economic performances and innovation among its members.

[8] The purpose of these policies is to measure a country's innovative activities, productivity and competitiveness. However, the OECD economic survey places great emphasis on R&D based indicators in analysing economic performance. As such, countries are mapped in terms of patents, innovation, and amount of R&D spent on innovation activities. Many scholars have shown that R&D statistics do not capture the dimension of all industries' structures, because technologies and innovation intensity differ among industries, and industries' structures differ from country to country (Malerba , 2002; Malerba , 2004; Breschi, et al., 2000; Fagerberg, et al., 2005).

Although NIS is a strong framework for understanding the relationships between institutional and production structure within the innovation system, other scholars (Cooke, et al., 1997; Asheim & Isaksen, 2001; Asheim & Isaksen, 1997) have discovered that innovation also operates at the regional level, and that regions are the stages of social interaction and economic performances[9] (Regional Innovation System - RIS). These scholars have elaborated on spatial proximities[10] and cultural variable as the fundamental elements in innovation process (Asheim & Gertler, 2005). Since innovation is institutional, political and social, the rules that govern these changes are derived from social and economic factors such as culture, rules, norms and values. In short, firms within the same region share commonalities in institutional rules and routines. This was well illustrated in the study of regional development of Norwegian PV TIS conducted by Klitkou & Coenen (2013). The study analysed the presence of proximity advantage in the development of the Norwegian PV TIS in the western, northern, eastern and southern regions. In this study, RIS served as a great way of mapping the spatial pattern of regional industrial development in the Norwegian PV TIS. It shows that innovation is locally embedded, and firms produce new knowledge through localised learning processes stimulated by social, geographical and cultural proximity (Cooke, et al., 1997; Asheim & Isaksen, 2001; Asheim & Isaksen, 1997).

Analysing the Norwegian PV TIS from a regional perspective shows that regional resources and competition stimulate innovation activities. It provides an understanding of innovation dynamics in regional economy. This delineation of innovation system can guide policy makers in promoting and improving innovation capabilities and performance among local firms. However, this approach also focuses more on the structural elements and less on the dynamics and innovation processes. Therefore, other scholars have studied the dynamic of sectoral (The Sectoral Innovation System) innovation and technological change (Malerba , 2002; Malerba , 2004; Malerba, 1999; Pavitt , 1984; Robson, et al., 1988). According to these scholars, the sectoral dimensions influence the innovation and technological change, because the characteristics of technological change, innovation processes and economic performance differ across sectors (Fagerberg, et al., 2005). Although, sectors play important roles in a country's innovation and economic performance, they have different economic roles within the national system, and they are characterised by specific technologies, knowledge base, inputs and demand (Malerba , 2004).

[9] The RIS approach is similar of the NIS, and focuses on *learning* and *institutional structures*. RIS is defined as the *"the institutional infrastructure supporting innovation within the production structure of a region"* (Asheim & Gertler, 2005, p. 299).

[10] Geography matters because firms within the same region interact and encourage each other to produce new knowledge in order to remain competitive.

The Sectoral Innovation System (henceforth SIS) approach emerged as a critique of NIS approach[11] (and RIS). Fagerberg and colleagues argued that the NIS approach focuses on the differences of economic performance across countries without drawing attention to national growth patterns (Fagerberg, et al., 2005). Since there is an interaction between the national and SIS, the SIS framework analyses the local, regional, national as well as global dimensions of the innovation system in order to understand the driving forces of competitions across sectors (Fagerberg, et al., 2005). For instance, by analysing the dynamics and the need of green competence in the Norwegian PV industry, Klitkou (2010) explored the boundaries and the structures of the PV industry and the interactions between the actors[12]. The framework recognises that there are few large companies competing at the national and global levels in some industries, and large numbers of small companies that are geographically scattered in some industries. In this sense, the boundaries of SIS emerge from the specific condition of each sector (Malerba , 2002; Malerba , 2004; Malerba, 1999; Pavitt , 1984; Robson, et al., 1988). As illustrated in some studies (Klitkou & Godø , 2010; Ruud & Larsen, 2005), analysing the interactions between key actors in the Norwegian PV industry helped assess the key driving forces in national growth and patterns of innovation process.

The foregoing IS approaches can be categorised into two groups. The first group focuses on the geographical boundaries (national and regional) of IS. The other group focuses on the technological and industrial characteristics of a sector (sectoral boundaries). The SIS and TIS can be placed within the second group. The following section will review the critics of the foregoing approaches, and analyse *why* and *how* TIS is better suitable for analysing the development and emergence of the Norwegian PV TIS.

4.3 CRITICS OF THE IS APPROACH: WHY TIS APPROACH?

Most of the IS approaches focus on "institutional structures" and "learning", where innovation is seen as a system of institutional structures driven by economic process through the production of knowledge. The foregoing IS approaches have received many criticisms on several points. First, the IS approach is highly determined by institutional infrastructures, where the purpose is to compare the social structure that underpins the learning dynamics of a system. Often, these approaches (NIS, RIS and SIS) focus less on the dynamics of the system (Hekkert , et al., 2007), which is fundamental in understanding the development

[11] While the NIS approach maps innovation activities in terms of R&D indicators, Scholars of SIS argued that R&D intensities, market structure and firm sizes are endogenous to the characteristics of a sector's knowledge (Markard & Truffer, 2008; Malerba, 1999; Malerba , 2004; Malerba , 2002; Breschi, et al., 2000). As such, they have differences in the process of knowledge creation.

[12] Malerba (1999) argued that sectoral system pays attention to knowledge creation and its structures. Sectoral system is an important aspect for innovation research, because it provides an understanding of innovation implications and policy measures.

of technological change. Second, it is difficult to assess the dynamic of a system at the national, since there are several structure components in a country. These critics have led to the development of Technological Innovation System (TIS) approach, in which emphasis is placed on specific technologies (Jacobsson & Johnson, 2000; Carlsson & Stankiewicz, 1991; Hekkert , et al., 2007; Negro , et al., 2007; Bergek, et al., 2008a).

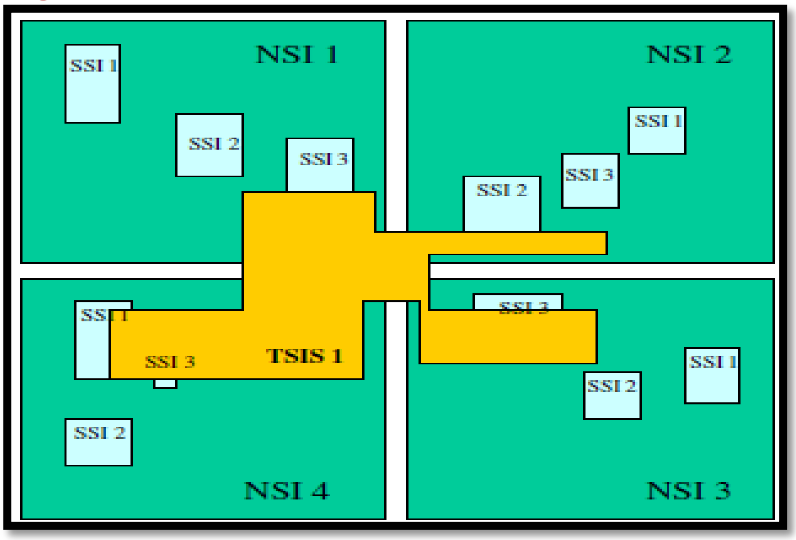
TIS is a concept developed within the literature of IS, and it emphasises on the nature and dynamics of technological change (Hekkert , et al., 2007). Understanding technological change involves an understanding of both external and internal dynamics of the system. The configurations of the foregoing IS approaches make it difficult to map such dynamics, since the aim of this inquiry is to understand the dynamics, development and emergence of the Norwegian PV TIS. The focal point of this thesis is not a geographical or industrial, but a Photovoltaic technology: a technological system. The focus is to understand the development a novel technology and the dynamics of innovation process. Moreover, the dynamic of technological change is not only determined by institutional infrastructures (Hekkert , et al., 2007), but also by the competition between novel and incumbent technologies and the dynamics of innovation processes (Bergek & Jacobsson , 2003; Hekkert , et al., 2007; Negro , et al., 2007). In other words, the emergence of novel technology is a slow process (Bergek, et al., 2008a), because RNE sources have to compete with network externalities of incumbent technologies (Markard & Truffer, 2008). In their initial phases, diffusion process is slow and resources are limited (Bergek , et al., 2008b; Bergek, et al., 2008a). Therefore, they cannot immediately compete with established technologies (Rosenberg, 1976). This thesis argues that one needs to gain insights of system dynamics in order to understand the rate of technological change. The emergence, diffusion and development of novel technologies can be hence studied through the concept of TIS (Jacobsson & Johnson, 2000; Carlsson & Stankiewicz, 1991). This framework is especially suitable for understanding the development of the Norwegian PV TIS, because it takes a starting point from a technology. Focusing on the technology allows us to open the black box, and look inside in the system in order to examine its dynamics. It opens up the space for analysing the interactions between structures and innovation processes, making it possible to understand the emergence of Norwegian PV TIS, its blocking and inducement mechanisms. The next section will provide a review of the TIS literature.

4.4 TECHNOLOGICAL INNOVATION SYSTEMS

Since the seminal contributions by Pavitt (1984), Carlson & Stankiewicz (1991) Malerba (1994), analysing the dynamics of a specific technology has received attention among scholars and policy makers. While the SIS focuses on the innovation activities, structures and capabilities of a sector, TIS approach focuses on a specific technology. There are several reasons for analysing Technological Innovation System. First, there are several technological systems in a country, region or sector, and some actors are involved in several TIS (Jacobsson & Johnson, 2000). There are however, few structural components (actors, networks and institutions) in a specific technology (or an industry), which makes it much easier to map the structures of TIS (Bergek, et al., 2008a).

Second, the TIS approach allows the researcher to analyse the boundary of the system (Carlsson, et al., 2002), the innovation processes (Bergek, 2002) and mechanisms blocking or inducing the development of the system (Johnson & Jacobsson, 2001). Although TIS focuses on the technology, the technological systems intersect with parts of the national (as well as regional) and sectoral systems (Hekkert , et al., 2007). Figure 4.1 illustrated how TIS is related to the geographical dimensions of the national and sectoral systems. These boarders do not form the boundaries of the system (Carlsson & Stankiewicz, 1991), but the national, regional and sectoral systems influence the diffusion of TIS and the rate of are of innovation processes (Hekkert , et al., 2007; Bergek, et al., 2008a). In other words, TIS can be national, regional, sectoral, and international and even global (Carlsson & Stankiewicz, 1991).

Figure 4.1: The Boundaries of TIS



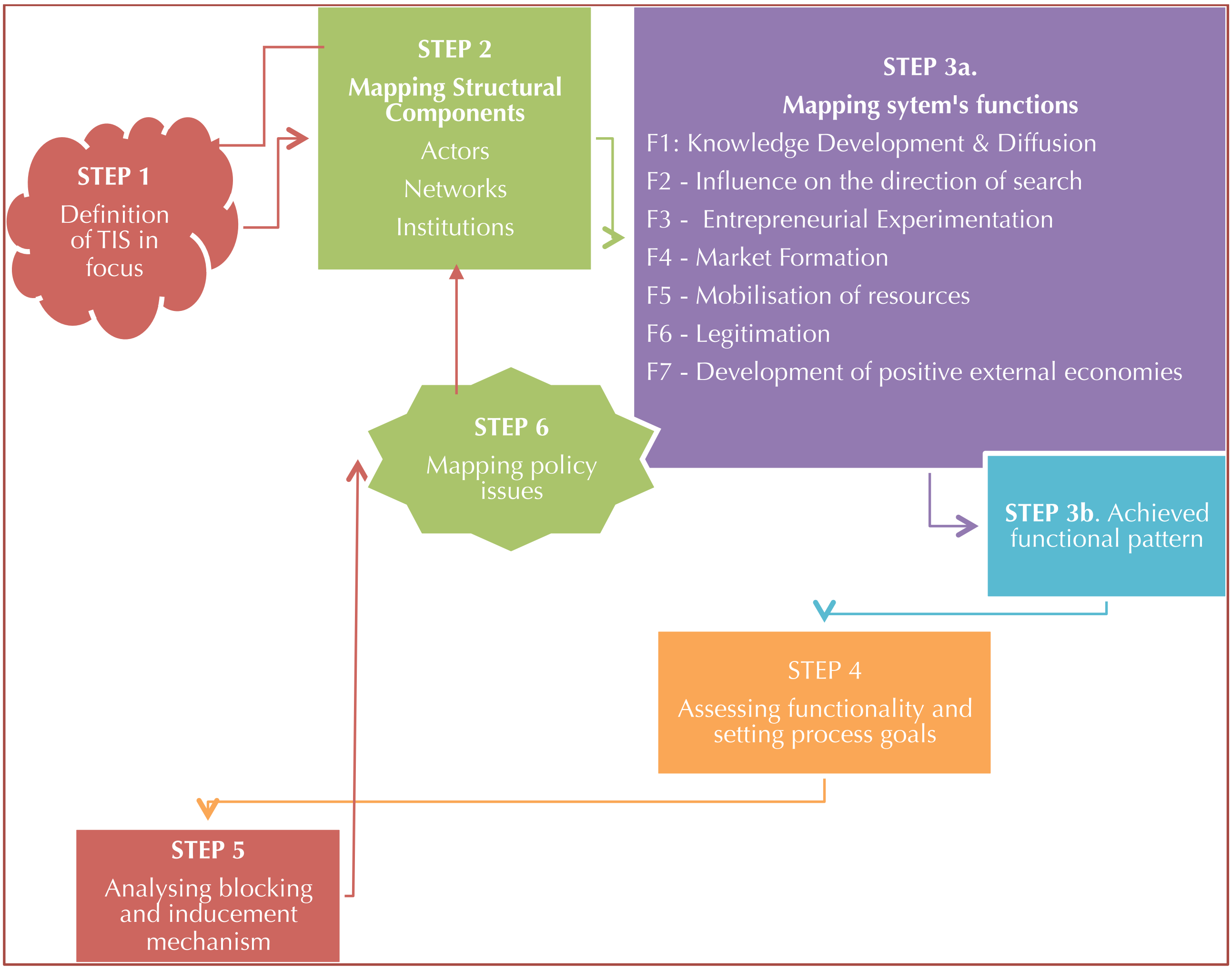
Source: Hekkert, et al. (2007)

In addition, the framework determines a system by a technology or a product, before setting its geographical boundaries (Jacobsson & Johnson, 2000). Furthermore, the system boundaries of TIS depend on the competence and capabilities of the agents, the market requirements and the selection mechanisms (Carlsson & Stankiewicz, 1991). Third, since the structures regulate the innovation processes, the TIS framework analyses both the structural performances and the innovation processes in order to understand the overall performance of the system. The framework makes it possible to separate the structure from the processes and content, and to analyse the weaknesses and strengths of the system (Jacobsson & Johnson, 2000), hence allowing the researcher to assess policy problems and goals (Bergek, et al., 2008a). This has been demonstrated in several empirical studies (Bergek & Jacobsson , 2003; Bergek, 2002; Bergek, et al., 2008a; Johnson & Jacobsson, 2001; Johnson & Jacobsson, 2001; Negro , et al., 2007; Hekkert , et al., 2007).

4.5 THE SCHEME ANALYSIS PROPOSED BY BERGEK

According to Bergek and colleagues (2008a), innovation system is an analytical tool for understanding the dynamics and performance of a system. In order to understand the dynamic of innovation, one must understand the structural infrastructures as well as the innovation processes within the system. Bergek et al. (2008) referred to these processes as "functions", and proposed seven functions that contribute to the development and diffusion of innovation. They proposed a scheme analysis of six steps for policy makers and researchers. The scheme analysis is the description of six analytical steps that need to be undertaken in order to map the dynamics of the system. The scheme analysis will be used as the analytical framework in this inquiry (see Figure 4.2).

Figure 4.2: The Scheme analysis (adapted from Bergek et al. 2008)



4.5.1 STEP 1: DEFINING THE TIS

The first step of the scheme analysis is to identify the boundary of the system (whether is a knowledge field or product). The analyst must make a decision between the unit of analysis and the focus of the study. Bergek et al. (2008a) outlined three choices: (i) the choice between knowledge field and product field, (ii) the choice between breadth and depth, and (iii) the choice of spatial domain. Setting a boundary is essential for defining the Norwegian PV TIS, and the research questions have guided the choices taken in defining the scope and boundary of the system.

First, the researcher needs to choose between product and knowledge field. The delineation of TIS is straightforward when the focus of analysis is product (Bergek, et al., 2008a). For example, one starting point of renewable energy could be PV or wind turbine. When the focus of the analysis is a technological knowledge field, a researcher will choose a focus that reflects the nature of the research question, whereas policymakers will choose a definition that suits their area of responsibilities. Second, the researcher needs to choose between the breadth and depth of the study. These two choices have the implications of which institutional components to include in the study (Bergek, et al., 2008a). The breath of the study is concerned with the level of aggregation of the study. This means that the researcher choose to include much in order to get a broader picture or choose more specific in order to get more details (Bergek, et al., 2008a). The analysis of the study may be limited to a specific application or include all applications. For this enquiry, it was matter of understanding all activities across all the spectrum of the value chain of the Norwegian PV TIS.

Third, the foregoing choices may have spatial focus. As mentioned earlier, TIS are global in character. Nevertheless, the researcher might focus on a spatially part of a particular TIS in order to capture the dynamics of the system. Bergek et al. (2008a) warned not to only use geographical delimitation, but to also focus on international elements of the TIS. This is because the global characteristics of the TIS cannot be comprehended without an assessment of the global context (Bergek, et al., 2008a). All these aspects are accounted for in section 5.1.

4.5.2 STEP 2: MAPPING STRUCTURAL COMPONENTS

Having defined the boundary and scope of the system, the structural component of the TIS should be mapped. After all, a technological system is a "Network of agents interacting in a specific *economic/industrial area* under a particular *institutional infrastructure* or set of infrastructures and involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz, 1991, p. 111). This definition of TIS shows that networks, institutions and actors (agents) are the essential elements in the diffusion and development process of a technology. These elements include actors, which include firms, organisations, government, research institutions and universities, networks as the platform for information exchange and knowledge development and institutions, which regulate the relationship between the actors and the TIS. Bergek and colleagues (2008a) proposed the analysis of structural components as the second step of the scheme analysis.

❖ Actors

First, actors of the TIS need to be identified. Scholars have extended the concept of entrepreneur to actors (Edquist , 1997; Lundvall, 1992; Nelson , 1993) to include all stakeholders involved in the development and diffusion of a technology. They do not only include firms in the value chain, but also research institutes, universities and other organisations and stakeholders contributing to the development of the emerging technology (Bergek, et al., 2008a). Knowledge, learning, values and norms are the characteristics of actors within the innovation system (Edquist , 1997; Lundvall, 1992; Nelson , 1993). Policy makers need to be especially concerned with the role of the "prime movers"; they must introduce policy measures that can stimulate the formation of new networks (Jacobsson & Johnson, 2000).

Prime movers are actors who are financially, technically and politically powerful enough to influence the development and diffusion of a new technology (Jacobsson & Bergek , 2004). They can raise awareness, undertake investment, provide legitimacy and diffuse the new technology (Jacobsson & Johnson, 2000). As illustrated in section 5.3, prime movers were allocated in the capital good industry, and guided the direction of the search at the initial stage of the Norwegian PV TIS. Some of these prime movers acted as educational platform in Glomfjord, Herøya and Årdal by providing training workforce. This is why the development of TIS depends on the presence, willingness and competence of actors, especially *prime movers* (Jacobsson & Johnson, 2000). Other key actors could be non-commercial organisation acting as promoters of the new technology (Jacobsson & Bergek , 2004) such as The European Photovoltaic Industry Association (henceforth EPIA).

❖ Networks

The second structural component within the TIS is that of *networks*. A Technological system is a large complex social system, composing of components, elements and relationships, which produce, diffuse and use of a technology (Carlsson & Stankiewicz, 1991; Carlsson, et al., 2002). Because of these complexities, firms do not innovate in isolation. They interact with other organisations, educational, research institutions, users and suppliers and even with competitors in order to develop and exchange knowledge, information and resources (Edquist , 1997). Lundvall (1992) stressed on the importance of these interactions in the production of knowledge. Exploring these relationships and their interactions during the process of knowledge development and diffusion is fundamental in understanding system dynamic. These types of interactions involve the relationships between actors, technologies and institutions.

Networking is also essential for the functions "entrepreneurial experimentation" and for the diffusion and creation of new knowledge (F1). Uncertainties can lead actors through a process of experimentation and search. This is where the role of networks becomes essential in mediating between firms and markets (Carlsson & Stankiewicz, 1991). They facilitate the exchange of information, and serve as providers of technical, political, or financial knowledge (Jacobsson & Johnson, 2000) during the transformation process. The role of networks in the transformation process is to transfer knowledge and influence the nature of the institutions. As illustrated in the Norwegian PV TIS (see section 5.2.2), networks are often informal rather than formal. In addition, they constitute the transfer channel for both tacit and explicit knowledge (Jacobsson & Bergek , 2004). There are different types of networks such as community of practice, learning networks, industrial networks, and user-supplier network. One example of user-suppliers network is that of Electronic Data Interchange (EDI), which involves the interaction between firms and supplier through the exchange of electronic information. It is however, worth noting that networks have different purpose, characteristics and boundaries, because members of the network have intentions and ambitions (Carlsson & Stankiewicz, 1991). For instance, although the Norwegian Research Centre for Solar Cell Technology (henceforth Solar United) was established to organise and strengthen the collective knowledge of the Norwegian PV TIS, partners of the network have different goals in regards to knowledge development (F1)

❖ Institutions

The third structural component in the scheme framework is the *institutional infrastructures*. The importance of institutions have been mentioned in all IS approaches; they are the core of the IS concept (Edquist & Johnson , 1997). Freeman's definition of innovation systems referred to "network of institutions", which diffuse new technologies (Freeman, 1987). Lundvall (1992) notes that the "institutional set-up" is the second most important element of the NIS. Nelson (1993) stresses on the importance of "institutional and production mechanisms" supporting economic change. Edquist (1997) also stresses on "institutional factors" that influence the development of innovation. Carlson and

Stankiewicz (1991) mention that TIS is "a set of institutional arrangements (both regimes and organizations) which, directly or indirectly, support, stimulate and regulate the process of innovation and diffusion of technology".

Johnson (1992) defined institutions as habits, rules, routines, norms and laws, which standardise relations between people. These institutional rules are fixed, but can change over time (Verspagen, 2005) by users or producers within the market. There is a distinction between *hard* and *soft* institutions. Capital market, legislation or educational systems are examples of the "hard" institutional infrastructures, while norms, values and culture are "soft" (Jacobsson & Johnson, 2000). The correlation between institutions and innovations is manifold; institutions are the forces that regulate the conditions of the TIS environment. They are the normative structures within the operational environment of the firm. Since the institutions regulate the relation between actors, the pattern of interaction among actors and their decision-making processes are affected by institutional set up (Lundvall, 1992). The role of institutions is to reduce uncertainties by providing information (Edquist & Johnson , 1997) in order to promote stable social interactions among actors (Johnson, 1992). They coordinate the use of knowledge, resolve conflicts and provide incentive systems (Johnson, 1992). By serving these functions, institutional structures can influence the directions of the innovation process. Therefore, examining the nature of structural dynamics and their impact on the innovation processes are essential in understanding system performance. In doing so, Bergek and colleagues (2008) have introduces key processes that influence the development and diffusion of novel technologies. These processes (or functions) are reviewed in the next section.

4.5.3 STEP 3: ASSESSING SYSTEM FUNCTIONS

The structural analysis of TIS provides insights into the features of the structural components, their relations and the conflicts that drives or blocks the diffusion and development of a new technology. However, the structural infrastructures change during the different stages of the TIS. These insights in the current (or the present) structural infrastructures are not sufficient in understanding the determinants of technological change (Hekkert , et al., 2007). Therefore, one must explore the processes of innovation in order to comprehend the mechanisms that need to be fulfilled for the system to evolve. For instance, section 5.4 demonstrates that structural components go through a process of transformation during the different phases of the Norwegian PV TIS. Since the process of change depends on the interactions between the institutional components and the innovation processes (Markard & Truffer, 2008), it is essential to map the activities that take places within the TIS (Hekkert , et al., 2007). Bergek and colleagues (2008a) proposed an analysis of these functions as the third step of the scheme analysis. The aim of this step is to analyse how the new technology is performing in terms of the key processes (Bergek, et al., 2008a), and to understand processes of technological change and innovation (Hekkert , et al., 2007). The functional analysis maps the innovation processes within the system. Since there are several innovation processes within the TIS, it is important to analyse the relevant functions. Functions are considered relevant when they stimulate the goal of the system (Hekkert , et al., 2007).

The functions presented in this section are adopted from Bergek et al. (2008a). However, there are other approaches of functional analysis (Hekkert , et al., 2007; Negro , et al., 2007) within the literature. For example, Hekkert and colleagues (2007) analysed seven functions[13] through the sequence analysis. Their approach conceptualised changes as sequence of events while Bergek and colleagues (2008a) focused on the use of qualitative data in analysing these functions. Bergek and colleagues (2008a) mentions that the analyst needs to describe how each function is fulfilled in order to provide a picture of "achieved functional pattern" (Bergek , et al., 2007). This involves mapping both the state of the functions and their determinants (Bergek, et al., 2008a).

The first function of the scheme analysis involves ***Knowledge development and diffusion* (F1)**, which deals with the creation of new knowledge (Bergek & Jacobsson , 2003), mechanisms of knowledge diffusion, "*learning by searching*" and "*learning by doing*" (Hekkert , et al., 2007). Lundvall outlines that "the most fundamental resource in modern economy is knowledge, and accordingly the most important process is learning" (Lundvall, 1992, p. 1). This means that knowledge development and learning are fundamental to innovation process. For evolutionary economist, knowledge development is related to the creation of variety (McKelvey , 1997), because it increases options within the system. This development occurs during a process of learning, which might take place within networks through conferences, workshops, seminars and meetings. These interactions can happen between scientists and entrepreneurs or policymakers and universities. In this case, network activities can be regarded as a precondition to "*learning by interacting*" (Hekkert , et al., 2007). Networks are therefore important characteristics for knowledge diffusion (Carlsson & Stankiewicz, 1991) and learning, because they are the source of information exchange (Hekkert , et al., 2007). In the case of the Norwegian PV TIS, knowledge was developed during the pre-production phase through "*learning by doing",* which improved production knowledge. While *"learning by interaction"* with users led to the creation of market knowledge), *"learning by searching"* happened through acquisitions of relevant

[13] Hekkert et al. (2007) proposed the following functions: Entrepreneurial activities, Knowledge development, Knowledge diffusion through networks, guiding of the search, market formation, resource mobilizations and creation of legitimacy.

technologies combined with internal and external R&D activities. These learning activities led to the creation of technological and production knowledge during the pre-production phase of the system.

While the first function deals with the creation of knowledge, the second function, ***Influence in the Direction of the Search*** **(F2)** deals with activities that influence the search of knowledge development and diffusion (F1). As such, this function represents the process of selection, and guides the searching process among actors (Bergek & Jacobsson , 2003). Since resources are limited, specific attentions are given to those products that meet the expectations of influential actors. Resource allocation, is the core of the innovation processes, because there will be insufficient resources without a selection process (Hekkert , et al., 2007). Shaping the selection environment will hence lead to the development of new technologies, which will break the old habits. This can influence R&D priorities and the direction of technological change (Hekkert , et al., 2007). The function affects both internal and external actors, and it can have both positive and negative feedback within system. (F3). A positive influence can lead to technology development, new regulations or put pressures on incumbent technologies. It can also lead to new financial investments, which in turn attract new entrants into the TIS. In the case of the Norwegian PV TIS, demand from the international market guided by local government created positive feedback at the initial phase of the system.

The success of this function is not only vital for "knowledge development and diffusion" (F1), because the selection process requires experimentation that generates variety in the system. The third function, ***"Entrepreneurial experimentations"*** (F3) is hence an essential function for system performance. The presence of entrepreneurial activities is an indication of the performance of a TIS (Hekkert , et al., 2007). Since the economic change starts with entrepreneurial actions, and then spreads to the rest of the economy, the fundamental force behind structural economic growth is the introduction of new method of production, new product, the opening of new market, new supply of raw materials, and new organisation forms of any industry (Hagedoorn , 1996). Schumpeter referred to this force of dynamic economic development, as "new combinations" (Hagedoorn , 1996), which is innovation (carried out by the entrepreneur). In another word, radical innovation is the engine of economic development, and the role of the entrepreneur is to translate these combinations (or radical innovation) into business opportunities (Hekkert , et al., 2007). This is why; experimentation is essential for reducing technological, financial and market uncertainties that follow novel technology (Carlsson & Stankiewicz, 1991).

An entrepreneur can be new entrant or an established company, diversifying its portfolio in order to remain competitive (Hagedoorn , 1996). As we have seen in the Norwegian PV TIS, the level of experimentations was high during the period between 1994 and 2007. In the later phase, new entrants experiments with all part of the value chain, and helped diversify the collective knowledge of the system.

Although, experimentation is essential for the creation of variety, the growth of a new TIS depends on a diffusion process, which requires the formation of markets. Institutional change is thus required to create markets for the emerging technology. The fourth function, "***Market formation"*** **(F4)** involves the creation of demand through the development of niche markets (Jacobsson & Bergek , 2004). This could be achieved through favourable tax regimes or consumption quotes (Hekkert , et al., 2007), which could help create competitive advantage for novel technologies. These stimulations may serve as "nursing markets" where learning takes place. During this phase, the size of the market is relatively small (Bergek, et al., 2008a), but the price of the new technology is improved and new customer preferences are formed (Jacobsson & Bergek , 2004). However, in the Norwegian PV innovation system, lack of market initiatives blocked the formation of a domestic market.

The nursing market may lead to a "bridging market", which gives room to increase volumes and number of actors (Bergek, et al., 2008a). The formations of nursing and bridging markets are paramount to the development of a TIS. They allow other elements of the TIS to fall into place, and provide an incentive for new firms to enter various parts of the value chain (Jacobsson & Bergek , 2004). Finally, mass markets may evolve, often a long period after the formation of the initial market. In a summary, market formation goes through three phases. In the first phase, nursing markets are created, in which learning take place. This phase leads to the second phase; bridging markets, where system performance is improved. In the third phase, the new TIS enter the mass market.

The development of new technologies means the end for established technologies. Markets, networks and institutions are strongly influenced by policy (Jacobsson & Johnson, 2000); they are part of the system (Carlsson & Stankiewicz, 1991), and influence the process of discovery and selection. They are not neutral, and they can fail to support the emergence and diffusion of new technology (Jacobsson & Johnson, 2000). This is why; the fifth function, ***"Legitimation"*** (F5) can be regarded as important process of market formation. This function assesses the acceptance of the new technology. For example, policy makers can adjust the institutional set-up to the favour of the novel technology by introducing policy measures that create positive feedbacks in the system (Jacobsson & Johnson, 2000)[14]. These measures can contribute to the process of changing the institutional framework by fostering the development of actors and groups (Jacobsson & Johnson, 2000). As illustrated in the Norwegian PV TIS, lack of political visions and expectations provided low legitimacy for the system, and hampered the formation of market in Norway.

Nevertheless, high legitimacy can create positive feedback in the function ***"Mobilisation of Resources"*** (F6), which is the sixth function. Financial and human resources are essential for all innovation processes. This function involves the allocation of [financial and human] resources (Hekkert , et al., 2007), which can induce and knowledge development (F1). The analyst must assess to what extent the TIS is capable of mobilising competence and capital through education (Bergek, et al., 2008a). Although, there is low legitimacy in the Norwegian PV TIS, a substantial amount of resources have been allocated to support the system.

Finally, ***"the development of positive externalities"*** (F7) such as free utilities, supplier networks, establishment of new business areas and services, is a key process in the formation and development of a TIS (Bergek, et al., 2008a). Entry of new firms is essential in this function (Bergek, et al., 2008a), because the new firms not only bring new technology and labour into the TIS, but they also reinforce the legitimacy of the novel technology (F5) and guide the direction of search (F2). The entries of new firms also mean the creation of new combinations (and niche markets), which will reinforce the formation of market (4). This function reinforces the other six functions, and indicates the dynamics of the system, since externalities increase the strength of the other functions (Bergek , et al., 2008b).

4.5.4 STEP 4: ASSESSING THE FUNCTIONALITY AND SETTING PROCESS GOALS

The goal of a system is to develop and diffuse new knowledge. The functional approach makes it possible to compare the performance of the system with different institutional components (Hekkert , et al., 2007). It also makes it possible to map key policy issues, and evaluate system performance in terms of how the functions are being fulfilled (Bergek, et al., 2008a). However, the functional pattern (the foregoing step) only illustrates *how* the TIS is functioning (Bergek , et al., 2007). In order to measure

[14] This is when advocacy coalitions can function as a substance. They put the new technology on the agenda by shaping the selection environment (F2), mobilise financial and human resources (F6) and create protective spaces through favourable tax regimes (F4), and by doing so create legitimacy for a new technological (Hekkert , et al., 2007). If successful, advocacy coalitions might become powerful enough to break the forces that prevail in incumbent technologies (Hekkert , et al., 2007). Nonetheless, the success of these coalitions depends on entrepreneurial activities (F3) and resource mobilisation (F6).

how well the functions are fulfilled (Bergek & Jacobsson , 2003), the analyst needs to evaluate the relative "goodness" of a particular functional pattern, by comparing the seven functions against two bases of assessment[15] (Bergek , et al., 2007). This involves comparing the seven key functions with two bases: (i) establishing the phase of the TIS in order to determine the functional pattern, and (ii) comparing TIS in other regions or nations in terms of system performance and functional pattern (Bergek, et al., 2008a). They proposed the combination of both assessments in order to balance each other's weaknesses. One additional method is employed in this enquiry: (iii) mapping the attitudes of actors.

In the first assessment, the development phase of the TIS is determined in order to map the functional pattern. Since the characteristics of "functionality" may differ between the phases of development (Bergek & Jacobsson , 2003), distinguishing between the formative and growth phase is essential when assessing the functionality of the system (Bergek, et al., 2008a). The functional pattern can be thus assessed in terms of the requirements of each phase (Bergek, et al., 2008a). According to Jacobsson and Bergek (2004), the formative and growth phases differ in terms of technical change, the patterns of entry/exit and the rate of market growth. The formative phase is characterised by small markets, various entrants, a range of competing designs and high uncertainty in terms of technologies, markets and regulations. In order to understand the conditions under which the formative stage emerges, the analyst should focus on the settings of market formation (F4), legitimation (F5), influence on the direction of the search (F2) and the development of external economies (F6) (Bergek & Jacobsson , 2003). In addition, experimentations and the creation of variety are paramount in this phase (Bergek & Jacobsson , 2003).

In the growth phase, there is a large scale of technological diffusion and expansions, in which market shifts to bridging market (or mass market). Shifting into bridging markets or mass market means that the price and system performance must be improved. Resource allocation (F6) becomes essential in reducing costs in order to exploit economies of scale. Here, the analyst needs to focus on entrepreneurial experimentation (F3), resource mobilisation (F6) and legitimation (F5) (Bergek, et al., 2008a). In other words, functional pattern may be assessed in terms of how it supports firm entry, creates variety, stimulates niche markets in the formative phase, and exploits resources in the growth phase (Bergek & Jacobsson , 2003).

In the second assessment, the focal TIS is compared with other regional or national TIS. For instance, Bergek and Jacobson (2003) have compared wind tribunes in Sweden, the Netherlands and Germany

[15] Bergek et al. (2008a) pointed out the need for further research in this area.

in order to understand functional pattern in different phases of an industry's evolution. The comparative analysis allows the researcher to gain insights of the dynamics of similar systems. This exercise is useful in estimating the type of development expected in the focal TIS as well as identifying the critical processes of the system (Bergek, et al., 2008a). The researcher is then capable of developing specific goals based on the phase and comparative analyses. These goals are seen as "process goals", and they can be expressed in terms of seven functions. They are also similar to the various activities pursued by actors and policy makers (Bergek, et al., 2008a). Moreover, the analyst needs to analyse under which conditions structural elements change, and how interaction between functions and structures can lead to positive (virtuous) or negative (vicious) feedback loops. In section 5.4, an attempt is made to measure the performance of the Norwegian PV TIS in terms of how the interaction between functions and structures contribute to achieve an overall goal, and how the structural elements influence the functions.

4.5.5 STEP 5: INDUCEMENTS AND BLOCKING MECHANISMS

The internal dynamics of the system is created by the interaction between functions. Functions interactions can be considered an essential condition for structural change (Hekkert , et al., 2007). As such, analysing feedback loops between functions allows the researcher to gain insights of internal system dynamic, and identify the mechanisms that block or induce the development of the new TIS. Bergek and colleagues (2008a) notes that the process in which the new TIS emerges; depends on inducement and blocking mechanisms from the structural components (external dynamics). According to these authors, blocking mechanisms are driven by structural elements, while inducement mechanisms are related to policy measures (Bergek, et al., 2008a). Jacobson and Johnson (2000) have also described key mechanisms of change during the processes of innovation systems. They mention that the development process of new TIS is underpinned by structural conditions such as the process of institutional change, and the emergence of prime movers leading the way in the process of transformation (Jacobsson & Johnson, 2000). In short, inducement and blocking mechanisms originate from markets, actors, networks and institutions. Market, networks and institutional failures arising in the transformation process can block the evolution of new TIS. Therefore, policy measures need to focus on stimulating the internal dynamics of the TIS, while reducing the strength of the blocking mechanisms arising from the external environment.

In addition, the process of institutional change can serve as blocking mechanism. For instance, the existing of institutional infrastructures and networks can hamper the process of creating variety within the new system (Jacobsson & Johnson, 2000). This is because actors within the existing system do not look for opportunities outside their natural habitat. Institutional set-up needs to change (Edquist & Johnson , 1997) in order to support the new technology. The process of institutional change and their alignment is important process (Bergek, et al., 2008a), in which the new technology is transformed (Jacobsson & Johnson, 2000)[16]. In short, the analyst needs to identify the inducement and blocking mechanisms in order to assess the direction of the new TIS. The inducement and blocking mechanisms (external dynamics) together with the seven key processes (internal dynamics) give an indication of how a the new TIS is performing.

4.5.6 STEP 6: SPECIFY KEY POLICY ISSUES

In the last step, the analyst identifies the key policy issues related to the mechanisms that block or induce a development of a desirable functional pattern. It is important to understand an innovation system in terms of a system and not only in terms of individual functions (Johnson & Jacobsson, 2001). The policy issues should therefore aim at improving poor functionality by strengthening and creating inducement mechanisms; and by weakening and removing blocking mechanisms (Bergek, et al., 2008a). Bergek and colleagues suggested focusing on innovation processes and "system failure" in terms of functional weaknesses when identifying the key policy issues (ibid). In short, analysing the functional pattern of the TIS helps identify blocking and inducement mechanisms, which is central for policy implications.

[16] This is how the influence of "prime movers" becomes essential in the promotion and the diffusion of the new technology (Jacobsson & Johnson, 2000). They can induce the development of the new TIS, because they can satisfy specific demand from local market, and easily change the institutional set-up (Jacobsson & Johnson, 2000). Policy makers need to be concerned with the role of the "prime movers"; they must introduce policy measures that can stimulate the formation of new networks (ibid).

5. ANALYSIS

"By three methods we may learn wisdom: First, by reflection, which is noblest; second, by imitation, which is easiest; and third, by experience, which is the most bitter" **Confucius**

The analysis of the Norwegian PV TIS is presented in this chapter. The chapter is divided into four sections. The first part sets the boundary of the TIS in focus by looking at the technology, the competence of the PV industry and the spatial domain. The second part analyses the structural elements of the Norwegian PV TIS. The third part maps the functions of the system as well as their strengths and weaknesses. Finally, the chapter closes with a summary of the functional pattern and goals of the Norwegian PV TIS.

The case of the Norwegian PV TIS is a great way of understanding the process of an evolution process. This chapter will illustrate that the system emerged through several years of experiments and expertise acquired from the silicon, aluminium and material industries. Despite lack of domestic market, Norwegians actors have managed to compete on the international stage. Unlike, countries such as Japan, Germany or Spain, the Norwegian PV TIS did not emerged or induced by public incentives. Rather, the combinations of market and technological knowledge and the interactions between users and produces as well as access to natural resources and strong industrial clusters determined the development of the Norwegian PV TIS. The chapter will also shows that lack of legitimacy from the government can hamper the development of a novel technology, especially one that competes with subsidised companies. Essentially, high competitions from low cost countries such as China made it difficult for Norwegian players to remain competitive in the international market.

5.1 DEFINING THE NORWEGIAN PV TIS

As mentioned in section 4.5.1, defining the TIS is significant in setting the boundary of the system. Bergek and colleagues (2008a) stressed on the need of setting the unit and scope of the TIS. They proposed on focusing on (i) knowledge and product field, (ii) the breadth and depth and (iii) the choice of spatial domain. As such, technology, value chain and geographical aspects are the underlying elements in setting the boundary and scope of the Norwegian PV TIS. Since the system boundaries of TIS depends on the competence and capabilities of the agents, market requirements and selection mechanisms (Carlsson & Stankiewicz, 1991), setting *the technological* boundary in this enquiry has been relatively linked to *the value chain*[17], the knowledge and industrial activities of the industry. In regards to *the technology*, the enquiry focuses on silicon-based solar cells[18], which is the core competence of the Norwegian PV TIS.

As for the value chain, interview conversations with actors revealed that actors' definitions of upstream and downstream activities differ from one another. For example, all the research players that have been interviewed categorised all activities from cells to systems as downstream activities. Ole Grimsrud, R&D Vice President in Scatec AS mentioned during our interview conversations that distributors, developers and owners have the tendencies of categorising all activities from silicon to modules as upstream activities. He proposed dividing the value chain of the Norwegian PV industry into upstream, midstream and downstream activities as illustrated in Figure 5.1.

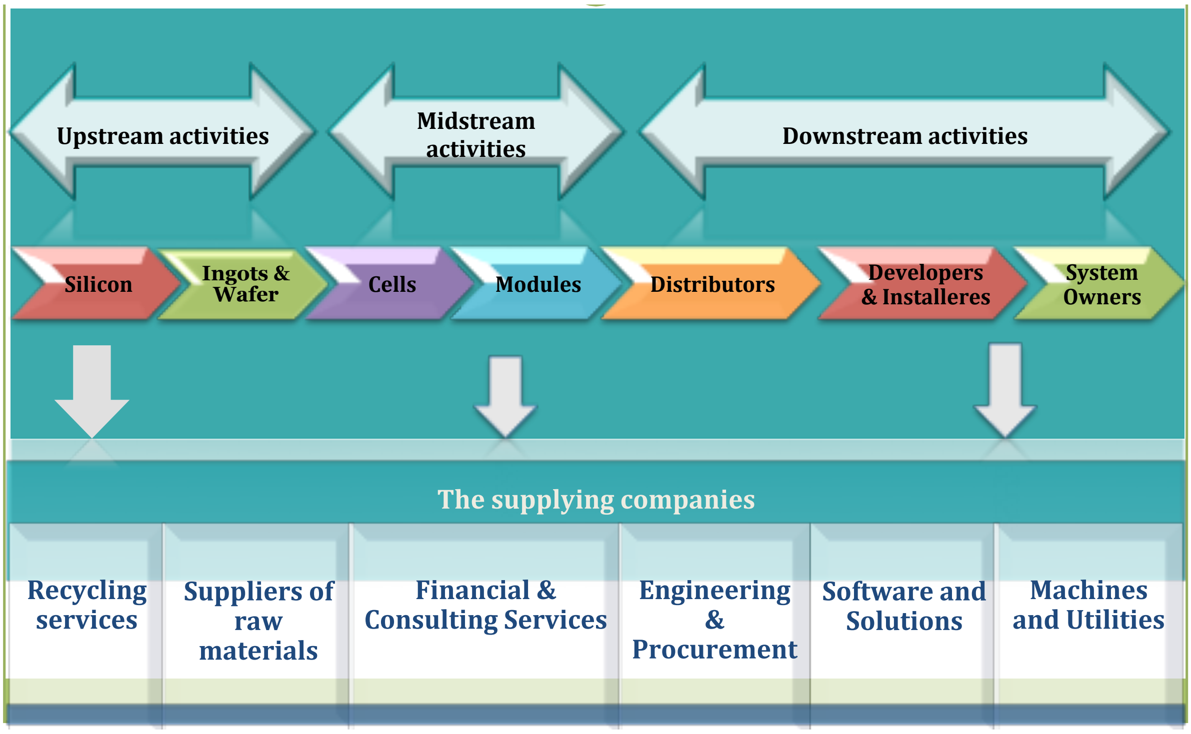
The system evolved to other parts of the value chain as knowledge spilled over from upstream players to several actors entering the midstream and downstream part of the value chain. For example, during the last seven years, new players such as Innotech Solar (henceforth ITS), Scatec Solar, Getek, Scatec Power and Fusion AS have entered the midstream and downstream part of the value chain (see sections 5.3.1.4 and 5.3.3). With this in mind, *the breadth* and *depth* of this study, include all technologies involved in the production of both mono and multi crystalline silicon cells (and modules) that are relevant for electrical energy, and all relevant related technologies such as recycling, distributors, developers of systems and supplying companies (as illustrated in figure 5.1). Electricity grid companies are excluded in the enquiry, because they do no have direct influence on the system. These choices are linked to the research questions, and will ultimately influence the analysis of the structural components.

In regards to the *spatial focus or geographical boundary,* the system will be delineated at national level, between the periods of 1970s to 2012. The upstream activities of the industry can be to certain degree limited to geographical boundary, because of the industry's distinctive competence developed from the production of silicon and wafer. All the upstream activities from silicon feedstock can be thus limited within national borders. Nonetheless, the Norwegian PV TIS emerged because of international demand for wafer. Although the technology in focus in this inquiry is limited to domestic activities, several of these actors are relatively linked to the international market as most Norwegian PV products

[17] A value chain is all activities involved in the production and sales of a product. These activities are normally divided into upstream and downstream activities. There is a distinction between crystalline silicon solar cells and thin film cells. Each of these two categories goes through relatively, similar processes in the value chain see section 2.2.1.
[18] The technology of silicon solar cells is explained in chapter 2, under the section Photovoltaic technology.

are exported. For example, companies such as Scatec have expanded their activities in the global industry, and major players such as REC and NorSun are now moving operations to Asia. Since one of the research questions seeks to assess the international characters of the system and its influence on the development of the Norwegian PV TIS, it is essential, not to only focus on geographical boundary of the TIS, but to also consider the international nature of the system. As such, focusing on national level will also involve looking at international activities involving knowledge development in terms of knowledge acquisitions in the creation of technological and production knowledge. The fact of the manner is that several informants, both industry and research actors agreed on the international characters of the Norwegian TIS. In summary, the Norwegian PV TIS consists of actors, institutions and networks, which produce and diffuse knowledge and technology in the development, and production of silicon based and thin film cells, modules and systems in Norway.

Figure 5.1: The value chain of the Norwegian PV Industry



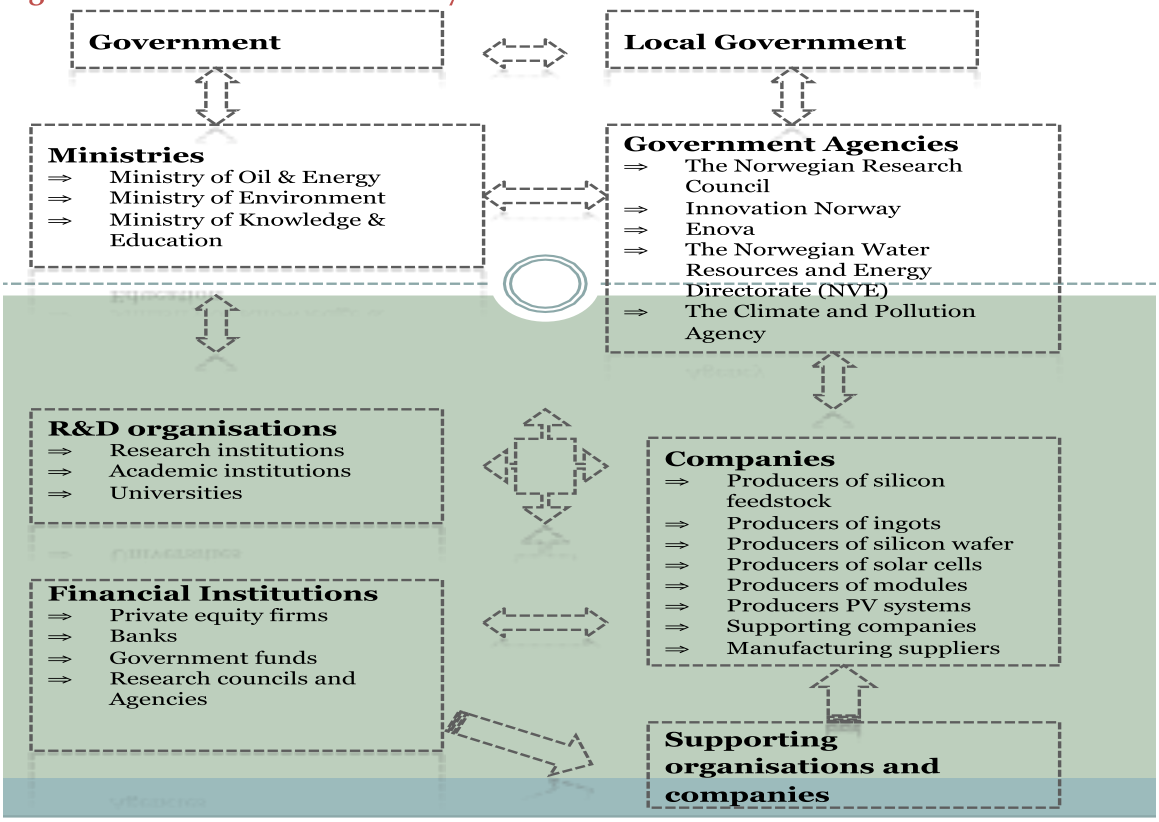
5.2 STRUCTURAL COMPONENTS IN THE NORWEGIAN PV TIS

In this section, the structural elements of the Norwegian PV TIS are described. Mapping the structure of the system has been a complex task, involving several steps of empirical research and interviews with key stakeholders from the industry and research environments. Although, Norway is a small country, the structural components of the PV system are complex and manifold. Three methods have been deployed in the process of mapping the structural element. First, the research questions served as a guiding step in setting the boundary of the TIS. There are significant structures within the Norwegian energy system, setting the boundary of the TIS to silicon-based solar cells, which is the core competence of the Norwegian PV TIS, has set the implications of which institutional components to include or exclude in the analysis. The second method employed in mapping the structures of the Norwegian PV TIS involved extensive document analysis such as industry, research and policy papers. The final and crucial method involved interviews with several informants, during which the snowball principle was applied. As mentioned in chapter 4, examining the role of the structural components and their impact on the innovations processes is essential in understanding system dynamics, because the structural elements regulate the innovative processes. This chapter will map these components.

5.2.1 ACTORS IN THE NORWEGIAN PV TIS

The process of mapping relevant actors within the Norwegian PV TIS has been a challenging, because the scope of actors within the system ranges from public actors to private actors, from manufacturing suppliers to users, from technological developers to technological owners, and from research institutions to non-commercial organisations. The development of the Norwegian PV TIS depends on the interactions between all these actors along the value chain. As pointed out by Bergek and colleagues (2008a), actors include all players along the value chain of the industry.

Figure 5.2: Actors in the Norway's PV TIS



During the empirical research, many informants described the relationship between research institutions and industry actors as "complimentary", because R&D and technological knowledge is created in collaborations between industry partners and research groups. Sections 5.2.3.2 and 5.3.1 will analyse the cultural dimensions of this relationship in the production of knowledge. First, the actors as illustrated in Figure 5.2, will be mapped and presented in details.

❖ Companies

According to Norwegian Renewable Energy Partner - INTPOW (2010), there were 32 companies operating in the Norwegian solar industry in 2010. These companies employed 4500 employees, and had a turnover of over NOK 12 billion in 2010 (ibid). Norwegian players have high expertise in the production and processing of silicon, and the strategies of the major players are reflected upon those competences[19]. Since the emergence of ScanWafer in 1994 – 1995 (Tronstad, 2012; Grimsrud, 2012), the Norwegian PV TIS has grown into substantial amount of small and big international players with activities across the value chain. As illustrated by figure 5.3, the players within the industry can be grouped into four categories.

The first group includes players involved in *upstream activities*, in the production of feedstock, ingots and wafers. Upstream players such as REC, Elkem Solar and NorSun were the first to establish in the Norwegian PV TIS (Tuv, 2013; Mühlbradt , 2012; Tronstad, 2012; Grimsrud, 2012). REC was a result of merger between ScanWafer, Solarenergy AS and Fornybar energy AS in 2000 (Ruud & Larsen, 2005; Klitkou, 2010; Klitkou, 2010). Through its subsidiaries, REC becomes the only Norwegian actor with activities across all the spectrum of the value chain, from silicon to solar cells (Foss, 2012). Elkem AS, the largest producer of ferrosilicon and silicon metal, which is wholly owned by The China International Bluestar (Stigset & Bhatia, 2011) is also another player within this group. Through its subsidiary, Elkem Solar manufactures and sells silicon for solar cell, namely Elkem Solar Silicon (ESS). The company had a production facility in Kristiansand with a yearly capacity of 6000 tons of silicon. Another producer within this group is NorSun AS, which is owned by Scatec AS. The company produces high capacity of mono-crystal silicon ingots from high purity grade (Grimsrud, 2012). Other small players include Fesil Sunergy (sold to Evonik), CleanSi and CruSiN (sold to Saint Gobain).

Players within the second group are involved in *midstream activities*, which is the production of solar cells and modules. REC and Innotech Solar AS (henceforth ITS) are the only players within this group. ITS produces cell and modules with a unique technological process, in which defects from off-spec solar cells are recycled and regenerated through a laser process (Tuv, 2013; Moen, 2012).

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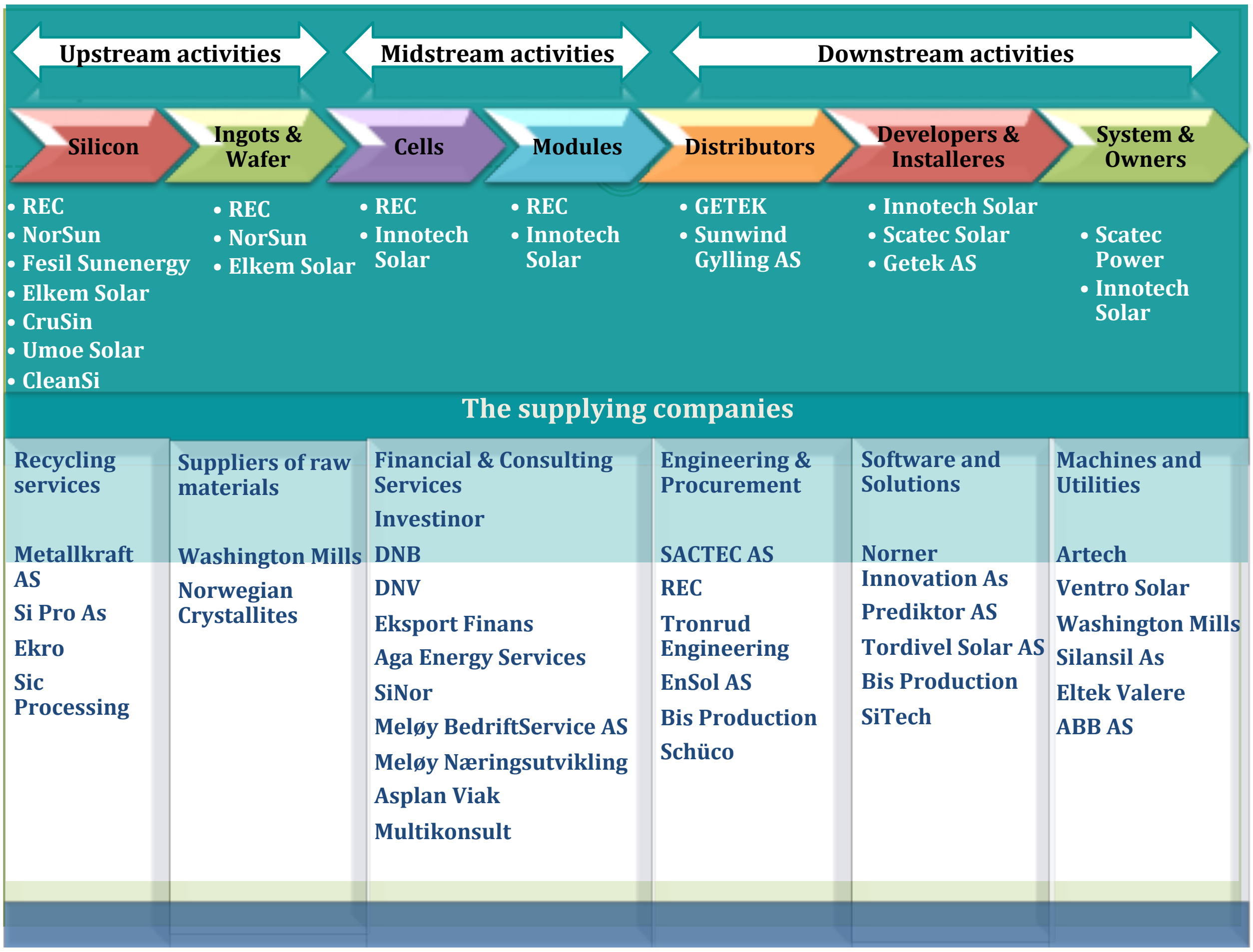
[19] Although Narula (2002) mentioned that the metallurgical industry is institutional locked-in, the emerging of the Norwegian PV is quite natural, taking into consideration that Norway has a competitive advantage in the production silicon and material processing technologies.

Figure 5.3: Players with the Norwegian PV TIS



The third group includes players who are involved in *downstream activities*. These players are involved in activities concerning PV systems and installations. They are the main customers of the aforementioned groups, and include distributors or wholesalers such as Getek, which are the intermediaries between manufacturers, the installer and individual customer; system developers and installers such as Scatec Solar and ITS, who build turnkey PV installations; and owners of PV installations such as Scatec Power, who sell power to the grid. ITS and Scatec Solar are the main players involved installation of PV plants. Both companies have international focus.

The establishment of the Norwegian solar industry has contributed to a supplying industry, including companies, which provides products, services and technology for players in the value chain. These players make up the fourth group of the industry, and mainly provide services and products to actors within the value chain. Some of these companies have developed into international players. These companies include Tronrud Engineering, Prediktor AS, Eltek Valere, Artech, Washington Mills, EnSol AS, BIS Production, Ventro Solar, Metallkraft AS, Sic Processing, Ekro and Si Pro AS etc.

Two factors remain relevant in understanding the interactions between all industry players and the emergence of the Norwegian PV TIS. First, it is evident that the companies who constitute the Norwegian PV TIS have developed substantial amount of knowledge and competence in the production and processing of silicon. The core of that knowledge was based on shared norms and values from the metallurgical, process and aluminium industries, in which the technology of solar was established. These expertise and competence developed from the silicon and metallurgical industries have spurred the willingness among prime movers such as ScanWafer, Elkem Solar, NorSun and REC who had both financial, technical resources needed to create, develop and commercialise new technology based on existing knowledge and expertise. Second, a matter of key importance is that the origin of the prime movers is reflected in the ownership structure, companies' strategies, the competitive environment and the relationship between industrial actors and research institutions. This relationship will be explored in section 5.3.

❖ Industry associations and organisations

Industry associations at the national level, such as the labour organisation Landsorganisasjonen (LO) has advocated on behalf of the PV industry. The Norwegian Associations of Solar Energy is another organisation involved in the promotion of PV in Norway. It creates a platform for learning and information exchange among industry actors and researchers. At the international level, The International Energy Agency (henceforth IEA) is responsible of promoting and coordinating economic development, environmental awareness and energy security in the world. The European Photovoltaic Industry Association (henceforth EPIA) is another international association, which represents the European PV industry. The role of most of the international associations in Europe is to advocate, and influence the direction of EU support for R&D. For example, The IEA Photovoltaic Power Systems Programme (henceforth PVPS) is one of the collaborative R&D Agreements established within the IEA, and the European Photovoltaic Technology Platform (henceforth EU PV Platform) is a research platform for European actors.

❖ Research institutions and universities

There are numerous silicon-based solar cells research activities at three universities in Norway, namely University of Aust-Agder (henceforth UiA), University of Oslo (henceforth UiO) and the Norwegian University of Science and Technology (henceforth NTNU), as well as at the research institutes, the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (henceforth SINTEF) and The Institute for Energy Technology (henceforth IFE). The Northern Research Institute

Narvik (henceforth Norut) is also involved in the research and development of silicon-based solar cell. The combinations of research activities among these players cover the entire value chain of upstream activities, ranging from silicon feedstocking, wafering and crystallisation to solar cell production, characterisation, modules and PV systems. Most of the projects carried out by the research groups are performed in partnership with industry players such as Elkem Solar, NorSun, Fesil Sunergy, REC and Scatec (Juel , 2012; Tranell, 2012; Foss, 2012; Grimsrud, 2012; Tronstad, 2012). In addition to the big players, small players such as NORUT[20] and Teknova are also involved in R&D activities. Teknova is a spin-off company, established in 2007 by the University of Agder and Agder Research (Imenes , 2012).

The research environments have established a strong relationship with major industry players. This relationship is based on the industry's competence, financial resources and expertise of the research institutions. The next section (5.3) will show how Norwegian research groups seek to exploit the industry core competence and technologies in the development of new knowledge.

❖ Governmental bodies and ministries

Governmental bodies have influenced both the structure and the dynamic of the Norwegian PV TIS. The four ministries mentioned in this section, are significant for market and energy regulations as well as industrial, regional and local development. The Ministry of Petroleum and Energy, whose main responsibility is to coordinate and create energy policies, has an objective of managing energy sources (Regjeringen, 2012a). It manages the country's water and non-fossil energy resources, through *The Norwegian Water Resources and Energy Directorate (NVE)* (ibid). The directorate is responsible of monitoring the energy market as well as providing maintenance of the national power supplies (NVE, 2011). In addition, NVE is involved in R&D and international development (ibid). *The Climate and Pollution Agency (Klif),* which is owned by The Ministry of the Environment, is another important player in the implementation and coordinating of environment and energy policies (Regjeringen, 2012b). The Ministry of the Environment is responsible for carrying out the government's environmental policies, and Klif carries out the implementation of pollution policy (ibid). One of the agency's activities includes reducing GHG emissions.

The Ministry of Local Government and Regional Development and The Ministry of Trade and Industry are also worth mentioning. The Ministry of Local Government and Regional Development is responsible of housing and building policy, regional policy, local administration and local government

[20] NORUT focuses on silicon production technologies, defect engineering in silicon wafers and solar cells, solar cell production technologies, high latitude PV power plant systems and building integrated solar energy systems (www.norut.no).

finances (Regjeringen , 2012c). The *Norwegian Building Authority* is one of the ministry's agencies, responsible of implementing building policy (ibid). The Ministry of Trade and Industry is responsible of creating frameworks for industry's policy as well as promoting trade, research, innovation and entrepreneurial activities (Regjeringen, 2012d). Ek*sportfinans,* the Norwegian institute for export financing, banks and state public institution, is one the ministry's companies (ibid). The company develops and offers financial services to the export industry.

❖ Government Funding Agencies and Companies

The government provides the framework for the major funding agencies, which promote research, innovation and entrepreneurship; and stimulate market. There are no specific public research schemes for supporting PV activities in Norway. These activities are funded within the existing funding framework, and there are four main players, who provide public schemes in Norway. All these players are strategically established to serve specific functions across the spectrum of research, industrial and entrepreneurial activities (Fahlvik, 2012; Mühlbradt , 2012; Moen, 2012; Heimdal, 2012; Grønli , 2012). Figure 5.4 illustrates the role of each player. The programmes allocated in the figure (5.4), will be analysed and discussed in section 5.3.

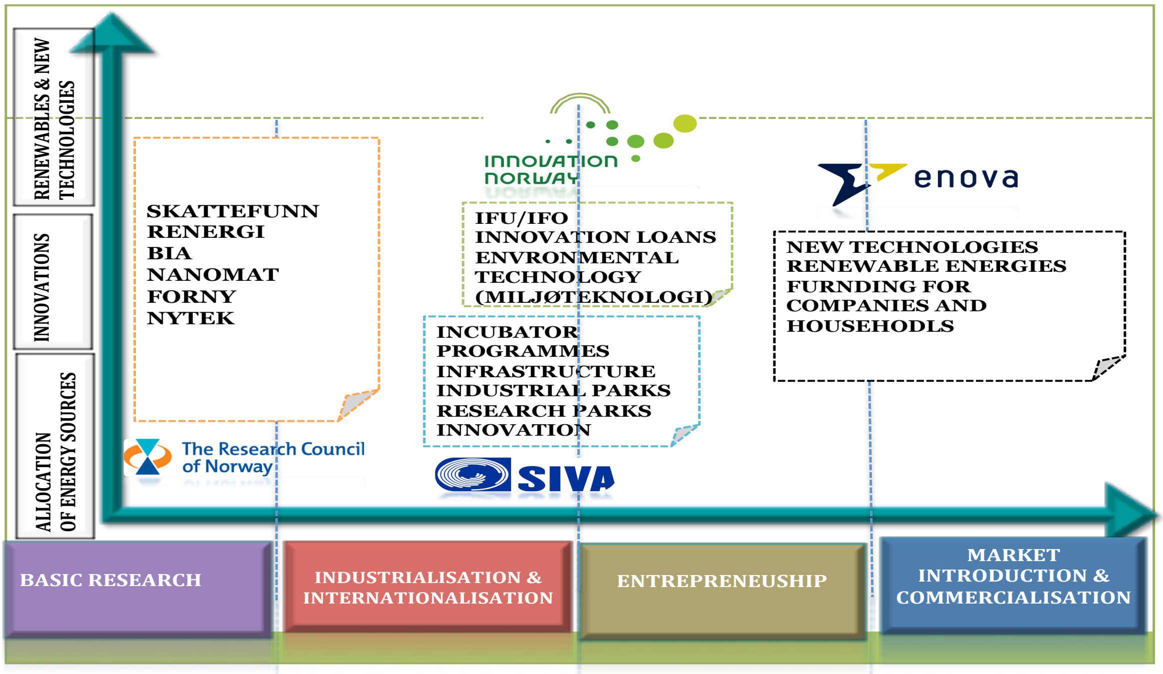
The Research council of Norway (henceforth RCN) plays a vital role in the development and implementation of Norway's overall research strategy. It functions as the main governmental advisory council, coordinator of research activities and as an administrator for funding R&D activities at universities and research institutions (Fahlvik, 2012). NRC funds R&D projects that have industrial benefit. As such, research institutions conduct projects in collaboration with industry partner. While the council's role is to promote R&D activities at research institutions and universities, the state owned company, Innovation Norway (henceforth IN) promotes industrial development and entrepreneurship. The agency also promotes innovation and contributes to internationalisation in different districts and regions in Norway[21]. Enova[22] is another state-owned company, which promotes energy consumption and generation. The company is owned by The Norwegian Ministry of Petroleum, which supports entrepreneurship, experimentation and demonstrations. The Industrial Development Corporation of

[21] In doing so, it provides financial advice and support through several of research schemes and financial loans. The *Environmental Technology program* (Miljøteknologi) is one of the company's schemes, which supports environmentally friendly products, production processes, resource management and technological systems, aiming at reducing environmental impact (Mühlbradt , 2012). *The Innovation Loan*, a risk loan is another way of financing of firms with profitable projects that are difficult to finance in the private credit market (ibid). The company also support new technology related projects.

[22] The company's activities are financed by the Energy Fund, which is financed by the income of the Basic Fund for Renewable Energy and Energy Efficiency.

Norway (SIVA) is also a national company, who adds value to government funding. The company develops regional and local industrial clusters through infrastructure, investment, knowledge and innovation. SIVA's main objective is to contribute to the achievement of the Norwegian government's policy goals in remote areas (SIVA, 2012).

Figure 5.4: Governmental funding bodies and funding programs



5.2.2 NETWORKS IN THE NORWEGIAN PV TIS

Networks play important role for the development and diffusion of knowledge in the Norwegian PV TIS. They determine the structure of the system, and they function as intermediaries between actors and markets. Moreover, they can increase the resource base of the firms in terms information, technology and knowledge (Jacobsson & Johnson, 2000), and influence the formation of market and selection mechanisms (Jacobsson & Bergek , 2004). Similarly, conversations with both industrial and R&D players suggested that participations in networks are strategic driven by factors such as competition, knowledge development and diffusion. There are few formal networks in the system, and they are mostly R&D based networks. These R&D networks exist through collaborations and strategic partnerships between industry partners, research institutions and universities both at national and international level. The biggest network of this calibre is The Norwegian Research Centre of Solar Cell Technology (Solar United), which organizes all Norwegian leading R&D groups (SINTEF, IFE, NTNU and UiO) and industrial partners such as Elkem Solar, NorSun, Scatec, Fesil Sunergy, REC, CleanSi and Innotech Solar (Solar United , 2012). The centre aims to create arena for industry, research and academic players in exchanging scientific based knowledge. A similar network is the Ferro Alloy industry's Research Association (henceforth FFF), which is cooperation between Elkem AS, Eramet Norway AS, Fesil, Finnfjord AS, Rio Doce Manganese Norway AS, Tinfos Ironworks AS and SINTEF-NTNU. The cooperation is based on long-term R&D and education, with the aim of developing new technologies and solutions to meet future international environmental standards as well as the production of silicon and new materials relevant for PV technology (Tronstad, 2012). Other network includes Norwegian Centres Expertise (NCE) Micro- & Nanotechnology.

As mentioned earlier, the formal networks are limited, partly because there are strong learning relationships among actors, which create an informal environment for information exchange and knowledge development. Collaborations are normally established to serve specific purpose or respond to common needs and demands. One of the network that exist to serve a common purpose is The Norwegian Research School in Renewable Energy (NorRen), which unites the PhD education within renewable energy at five of the Norwegian universities, NTNU, University at Bergen, UiO, University at Buskerud, University at Troms and the research institutions, SINTEF and IFE (SFFE, 2011). NorRen unites PhD candidates within renewable energy and enhance the cooperation between PhD candidates, universities and research institutions (ibid). In doing so, it organizes an annual summer school for PhD candidates and young researchers in Norway (www.norren.no). Networks with educational purpose are common in the system. For example, the University of Aust-Agder and Elkem collaborated in the field of education in the same way REC and Elkem cooperate with NTNU and SINTEF in order to increase competence and mobilise human resources (Klitkou, 2010; Tronstad, 2012).

Other formal networks include mergers and acquisitions (M&A), through searching, knowledge and resource acquisition both with international and national players, partnerships and collaborations as well as formal strategic partnership and alliances between players, industrial networks and research players. Strategic partnerships and M&A normally exist through searching and exchange of knowledge and information. During an interview with Alf Bjørseth, the founder and CEO of NorSun mentioned that there are few formal networks in the Norwegian PV TIS. He also mentioned that there are many informal networks in the system, and they are more interesting than the formal ones. Section 5.3.1 will show the importance of these networks in the creation and diffusion of knowledge.

At regional level, the Oslo Renewable Energy and Environment Cluster (OREEC) and the Eyde network are other important informal forums. Eyde Network for process manufacturing companies unites a diverse range of companies with different products and services (Tronstad, 2012). Through the network, members can collaborate within the field of research, education, innovation and knowledge development as well as dissemination of information within the process industry (ibid). Industry players such as Elkem Solar and Metallkraft are some of the partners of the network. OREEC is another regional network of research and education in the renewable energy and environmental technology in the Oslo region. The network create meeting place for actors, and facilitate collaboration between industrial and R&D players. There are strong education and R&D networks in the system. However, there is a general perception of weak or lack of political mobilisation. Some of the informants called for a joint political force or network that could advocate or lobby for PV activities in the political environment. The Norwegian Solar Energy Society (NSES) is the only network, which lobbies for political engagement to make renewable energy sources competitive. NSES also promotes the utilization of solar energy through conferences, education, research, technology development and marketing. INTPOW is another network, which could advocate and lobby for PV activities. The association is a non-profit network between Norwegian authorities and companies within the renewable industry, with the purpose of creating an arena for the internationalisation of the Norwegian renewable energy industry (Norwegian Renewable Energy Partners, 2010).

❖ International Networks

Both industrial and R&D players are involved in international networks. Participations in international forums are especially of importance for industrial players, since their main customer groups are located in the international market. As such, most central players are engaged in R&D projects in partnerships with international universities and research institutes, or in networks aiming at developing new technology. Other involvements in the international milieu include formal learning networks involving R&D activities and information exchange. The International Energy Agency (IEA) is one of the international networks providing such platform. IEA is an independent body within the Organisation for Economic Cooperation and Development (OECD), which carries out co-operational energy programmes among its members (IEA PVPS, 2011). The IEA Photovoltaic Power Systems Programs is one the agency's collaborative programs[23]. The International Renewable Energy Agency (IRENA) is also worth mentioning. The agency is an intergovernmental organisation with the aim of promoting transition towards renewable energy (IRENA, 2012). Norway is officially represented in IRENA through

[23] In the past, Sweco Norge AS, REC ScanWafer and IF have respectively participated in Task 11 "PV Hybrid System within Mini-Grids", Task 1 "Exchange and Dissemination of Information on Photovoltaic Power Systems" and Task 3 Task 3 "Stand alone PV Systems"(www.nfr.no)

the Ministry of Environment and Ministry of Petroleum and Energy. Similar networks exist in the Nordic region. One Example is the Nordic Centre of Excellence in PV (NoCE in PV), forum for educational and learning among Nordic R&D players. The centre is under the Nordic Energy Research, an institution that aims at promoting regional cooperation within the field of energy research (Holt, et al., 2008). NoCE in PV is a collaboration between seven different PV research organisations within the Nordic region; IFE, Danish Technological Institute, Helsinki University of Technology, NTNU, Uppsala University, Ioffe Physico-Technical Institute in St. Petersburg, and Tallinn University of Technology (ibid). The purpose is to strengthen the existing Nordic R&D network and develop it into a Nordic PV industry.

As mentioned earlier, political networks aiming at Norwegian authorities are weak. There are however, strong political networks and mobilisations toward European Union and the rest of the world. Several of Norwegian players are members of EPIA, which represents members from all spectrum of the value chain, from producers of silicon to PV electricity generators (EPIA, 2011). Participations in these networks are majors of importance in creating partnership, sharing information, participating in political mobilisation at the European level and developing new knowledge. Actors are also engaged in SET Plan through several initiatives, which brings together the research and industrial communities, with the aim of developing energy technologies at the European level. These initiatives include the European Industrial Initiatives (henceforth EII), The Solar Europe Initiate (henceforth SEII) and the EU PV Technology Platform[24]. The research institutes are also represented in the SET plan through the European Energy Research Alliance (henceforth EERA). EERA is an alliance of leading organizations in the field of energy research, aiming at strengthening energy research capabilities in the EU (Kristiansen, 2010).

In addition, the European universities are also vital part of the SET plan through EERA by the European University Association (EuA). The EUA has established its own energy-related grouping European Platform of Universities engaged in Energy Research (EPUE). The aim of EPUE[25] is to represent a

[24] In implementing the SET Plan, the European Industrial Initiatives (henceforth EII) and the European Technology Platforms (henceforth ETP) were established. The Solar Europe Initiate (henceforth SEII), launched under the EII, is an industry-led initiative with a long-term focus of Research Development and Demonstration (R&D&D) for PV in Europe (European Photovoltaic Industry Association and EU PV Technology Platform, 2012). The initiative is an alliance between EPIA, the European Photovoltaic Technology Platform (EU PVTP), the European Commission (henceforth EC) and member states. The EU PVTP is another independent body under the European Technology Platforms, which mobilises actors in the European PV system, with goal of realizing the European Strategic Research Agenda for PV (ibid).

[25] EPUE has created a mirror group for 13 Working Groups in SET Plan “Education and training Initiatives”, in which photovoltaic is among other energy a source (EUA, 2012). The purpose of the SET - Plan "Education and

collective voice of universities in regards to energy research in the EU (EUA, 2012). The Norwegian universities are mobilised through the participation in EPUE and the establishment of a national shadow group. Gabriella Trannel from NTNU mentioned being involved in the PV SET Plan Education program. Other members of EPUE include UiO and UiA. The common purpose of EPUE participation is to ensure that Norwegian research and education agenda are visible. The EU's industrial initiative in energy materials, Energy Material Industrial Research Initiative (EMIRI) is another important part of the SET Plan, and represents a significant potential market for Norwegian research communities and industry. Another important forum is the European Research Area (ERA), which is a key priority for the internationalization of Norwegian research. Norwegian Energy Research Alliance (NERA) was enacted in 2011 (NCR) to operate as a "shadow group" to safeguard Norwegian interests towards ERA, and serves as an arena for Norwegian lobbying against ERA. NERA has all the major universities and research institutes such as NTNU, IFE, SINTEF and UiO are in the mirror group (www.nfr.no). The purpose is here is to develop national goals and strategies for Norwegian participation in European research cooperation and incentives that promote knowledge development and diffusion (ibid).

5.2.3 INSTITUTIONS IN THE NORWEGIAN PV TIS

As mentioned in chapter 4, the institutional frameworks regulate the relationship between actors. Therefore, they have great impact on the direction and the rate of innovation activities (Lundvall, 1992). These frameworks include culture, norms, routines, law and legislations, and their roles are to reduce uncertainties, provide incentives, manage conflicts and induce cooperation among actors. The research process has revealed that regulatory framework is significant in affecting the amount of resources devoted to innovation. As illustrated in the section 5.3.2, regional industrial policies were great inducement mechanisms during the establishment phase of knowledge development and diffusion. A key importance is that institutions need to guide both networks and actors in order to facilitate development of the TIS. Essentially, the institutional frameworks need to adjust themselves to the new TIS in order for it to develop (Bergek, et al., 2008a). This section will show that the Norwegian PV TIS operates within the existing frameworks and other regulations targeted at the renewable energy sources. This is because there is no regulatory changes have been explicitly implemented to support the development of the Norwegian PV TIS. Moreover, it will discuss the implications of the formal frameworks (laws and regulations) as well as the impact of the soft frameworks (cultures, norms and routines).

Training Initiative" is to create a foundation so that actors can plan education and training for the future energy markets (ibid). EPUE aims to provide input to the EU SET-Plan in the energy field.

5.2.3.1 LEGAL AND REGULATORY FRAMEWORKS OF THE SYSTEM

The regulatory framework must be viewed in two perspectives. First, it must be viewed in line with the government's attitudes and ambitions towards industrial development during the initial stage of the Norwegian PV TIS. Second, it must be viewed in line with the Government's aim and goals in becoming carbon neutral by 2050 (St. meld. nr 34, 2006-2007). These two perspectives are inter-connected, and must be analysed as such. Evidently, Norway's regulatory frameworks focus mainly on climate change and the reduction of GHG emissions. These directions led to a combination of tree policy instruments that promote renewable and environmental friendly technologies: (i) economic framework including financial policy instruments that promote and support renewable and environmental technologies as well as industrial development, (ii) strategic framework, which promote and coordinate R&D activities in renewable and environmental technologies and (iii) legal framework which, regulates and promote electricity production and consumption. The combinations of these three policies instruments constitute the hard institutional framework of the Norwegian PV TIS.

In regards to economic policy instruments, Norway does not have financial policy specifically targeted at PV technology. Most financial instruments allocated to the system were targeted at environmental friendly, Nano and new material technologies. Financial incentives promoting R&D activities for the development of energy system, funded by the Ministry of Petroleum and Energy and innovation related programmes targeted at industrial development in the silicon and material processing industry, funded by the Ministry of Trade and Industry supported R&D activities for the production of solar cells. These programmes were organised by RCN in collaboration with industry partners. From 2008, Climate Agreement adopted in 2008 became the main element of the regulatory framework.

In January 2008, the Norwegian Parliament made a Climate Agreement when adopting the Report No. 34 (2006-2007) "Norwegian climate policy". The agreement sets goals for Norway's efforts to reduce GHG emissions in the Kyoto Protocol's first commitment period (2008-2012) and continued until 2020 and 2030 (Innst. S. nr. 145, 2008). The general agreement was to reduce emissions in Norway by 15-17 million tonnes of CO2 equivalents by 2020 (ibid). In summary, Norway aims to be carbon neutral by 2050 (St. meld. nr 34, 2006-2007). As part of the implementation of the agreement, and as stated in the climate policy, the Norwegian government agreed that it would by 2010; assess measures and methods needed in achieving the targets. In June 2008, the Ministry of Climate and Pollution Agency appointed a research group namely; Climate Cure 2020, an inter-ministerial expert group with the mandate to analyse and recommend strategic action plans in reducing GHG emissions. The analysis in the report was based on the target for national emissions cuts stipulated in the Climate Agreement of 2008 and the Report No. 34 (2006-2007) "Norwegian climate policy".

The Climate agreement contributed to the implementation of several research strategies, three of which are relevant for the Norwegian PV TIS. After the agreement, The Ministry of Research and Education has appointed a national climate research strategy, Climate 21. The strategy sets out three priority areas; climate system, the impacts of change and adaptation and the reduction of GHG emissions (Klima21, 2010). It laid the foundation for the RCNs priorities within climate and renewable research programmes. Most importantly, Energy21, the national energy strategy for research, development, demonstration and commercialization of new energy technologies was also established in 2008. The strategy is the result of close cooperation between government, research and industry actors. Other relevant strategic framework includes the government strategy on the development and use of environmental and sustainable technologies. In 2011, the Ministry of Trade and Industry and the Ministry of Environment also published another strategy, "Economic Development and Green Growth" with the aim of strengthening R&D activities in environmental technologies. All these strategies are part of the government's strategic actions in promoting and increasing R&D activities in the areas of renewable and environmental friendly technologies that will contribute to the reduction of the GHG emissions. As illustrated in the study conducted by Klitkou and Godø (2010), PV technology is mainly supported through R&D public funding in Norway.

❖ Legal Framework: Electricity Production and Consumption

In order to increase and accelerate the diffusion of renewable electricity, the government has taken some legal measures in promoting and increasing the consumption of renewable energies. Since March 2010, NVE has implemented the "Surplus Plus Customers" incentive; a market push initiative in the end-user market that promote electricity consumption. This initiative is well suitable for owners of passive houses with PV panels or other renewable sources. NVE defines the "Surplus Plus Customers" as:

> "End-users of electricity that have an annual generation that normally does not exceed their consumption, but have during certain hours a surplus of electricity that can be fed back to the grid. Generation, which requires licensing or producers that supply electricity to other end-users are not covered by the dispensation" (NVE, 2011).

The incentive is targeted at end-users who produce electricity for self-consumption, and have energy surplus. With the Surplus Plus Customers, users can sell the electricity surplus back to the grid, to their local network company. When it comes to market failure initiative, Norway has implemented Green Certificates instead of FITs. Under the Electricity Certificate scheme, Norway and Sweden have a target of increasing power generation from renewable sources to 26.4 TWh by 2020 (NVE, 2011). Producers of renewable energy, such as photovoltaic systems can apply to electricity certificates. However, as argued in section 6.4, the scheme cannot help stimulate a PV market in Norway, since it is technological neutral and there is cheap access to hydropower in Norway. The scheme will last until 31st December 2035, and the support for production is independent of whether the facility is located in Norway or Sweden. The certificate is issued for 15 years, and the plant must have been constructed after 7th September 2009 (ibid), and meets the requirements for monitoring and reporting in accordance with the law on electricity certificates.

The Electricity Certificates scheme can play a vital role in Norway's achievement of the EEA Renewable Energy Directive. Over the years, the governments of most European countries have introduced large-scale of policies, aiming at increasing the production of renewable energy. In 2001, the EU adopted the RES-E Directive in order to promote the consumption of electricity from RNE sources. Under the directive, Member States are required to adopt national policies in which, 20 per cent of electricity consumption in 2010 are generated from RNE sources (European Union Committee, 2008, p. 10). The directive was implemented in Norway in 2011, through the EEA Agreement of Renewable Energy Directive (2009/28/EF). Norway's target in the agreement is 67.5 percent RNE by 2020 (The Ministry of Environment, 2011).

In regards to policy push instruments, the EU Building Energy Directive is another important legislation that could stimulate the PV market in Norway. The EU Building Energy Directive of 2002 was an important framework both in the EU and EEA. In the original directive, which is part of the EEA Agreement, there was a demand for energy labelling (St. meld. nr 21, 2011-2012). EU revised the 2010 building energy directive in 2012 in order to improve the performance of climate targets. The revised Building Energy Directive requires "nearly zero energy buildings" by 2020 and 2018 for public buildings (The Ministry of Pretroleum and Energy, 2012). In addition, the directive contains detailed provisions on energy requirements, energy labelling of buildings and energy assessment of technical systems. This requires the reduction of energy consumption, and increases the use of renewable energy sources such as solar panels. Norway has not yet taken a position on the revised building energy directive EEA (ibid). However, the directive could set the premise for Norway's policy in this area and could be an important input in construction requirements. Another relevant policy includes the energy requirement in the Technical Regulations for the Planning and Building Act. The act has been strengthened in recent years, and prohibits the installation of boilers of fossil fuels for base load in heating systems (The Ministry of Pretroleum and Energy, 2012).

5.2.3.2 THE CULTURAL FRAMEWORK

As mentioned in the literature chapter, innovation is essential for economic growth, and the development of new technology is preconditioned to the alignment of institutional framework. Nevertheless, barriers to innovation are often embedded in the informal institutions such as culture, norms and values, because they shape national, organisational and individual patterns in dealing with innovation and change. Essentially, culture is a contributing factor in innovation and knowledge management. The purpose of this section is to analyse how the innovation culture influence the Norwegian PV TIS, and how actors respond to these changes.

The context of innovation culture in this section refers to norms and values, which influence the process of innovation. It also denotes the overall national, organisational and individual attitudes toward change, innovation, entrepreneurship, industrialisation, self-employment and technology. According to Hofstede, national culture is "the collective programming of the mind which distinguishes the members in one human group from another" (Hofstede, 1991, p. 21), and the organisational culture is "the collective programming of the mind, which characterize the members of one organization from others" (Hofstede, 1991, p. 237). He defined symbols, rituals, heroes and values as the "collective programming". The concepts of symbols, rituals, heroes make up the practices, which are the core of an organisational culture. In regards to practices, section 5.3.3 will shows that Alf Bjørseth is the hero of the Norwegian PV TIS. According to several informants, he is one the factors that contributed to the establishment of the PV industry in Norway. Values are the core of the national culture; they are embedded in our societies, and contribute to the way individuals make decisions (Hofstede, 1980). Ultimately, the fundamental values in a national culture are simulated in the institutions through the practices of individuals (ibid).

In respect to Hofstede's four dimensions[26] (see footnote), Norway is a moderate collectivistic society (Hofstede, 2001). This collectivism is well reflected in Norway's strong collective social structure and welfare system. In regards to innovation, the contribution and the reward of being an entrepreneur, or self-employed (companies) in Norway is distributed through the social welfare and taxation system. Subsequently, people's ability and creativity to innovate is stimulated not only by organisational practices, but also by national values. Similarly, interview conversations with actors have pointed out that the national culture affects the innovation process, entrepreneurship and industrialisation, because

[26] According to Hofstede (2001), the differences between cultures can be captured by four dimensions; power distance, uncertainty avoidance, individualism-collectivism, and masculinity-femininity.

national culture shapes organisational practices in dealing with innovation and technology. There are strong opinions in terms of individual's attitudes toward risks associated with self-employment. For Example, Helle Moen pointed out:

"It is very easy to start business in Norway, and there are several financial supports for starting up a company. Nevertheless, it is natural that small businesses have a short life in Norway. There are far too many who are afraid to try. Taking chances is not something you need to do to survive in Norway because the earnings potential is much smaller than many countries." (Helle Moen, Empirical Interview 29.11.12)

The statement from Moen is a good illustration of how Norwegians' attitudes and behaviours towards opportunities and risks associated with entrepreneurship and self-employment; are affected by national values and social factors. One contributing factor in explaining Moen's argument is that taxation requirements in Norway influence people's decisions between *"being an employee"* or *"being self-employed"*. Self-employed are entitled to lower social benefits, because their contributions to social security is relatively low. Nonetheless, it is possible for self-employed to establish a private limited company and employ themselves, so that they can receive social benefits as an employee. Although, the national culture stimulates innovation and entrepreneurship, it is averse in regards to the success of industrialisation and individual economic success. One factor is that being "self-employed" or entrepreneur in Norway is less attractive, because the tax system makes it difficult for individual to be rewarded. In addition, individual private wealth is not admirable in Norway (OECD, 2008, p. 24). These collectivistic trends are also well reflected in the Norwegian PV TIS. At the initial stage, several players entered the Norwegian PV TIS because of the economic potential. However, many of those players must exit the industry not only because they lacked knowledge or competence to remain competitive, but also, because it is difficult for companies to survive at the industrialisation stage. For example, Gabriella Trannel mentioned that:

"Industry culture is very difficult in Norway. There are many companies with high international ambitions, but Norway lacks the industry culture that can make those ambitions possible. Big companies such as Statoil and small attractive, innovative and effective companies can survive. It is nevertheless, difficult for medium size companies to survive, especially in an industry such as PV, which requires resources and intensive expertise. The tradition of industrialisation is not so strong in Norway." (Gabriella Trannel, Empirical Interview 16.11.12)

Similar to the statement of Trannel, allocating resource and expertise in the Norwegian PV TIS depends on establishing networks, which may not be easily accessible for small companies. As sections 5.3.6 and 5.3.7 will show, the relationship between industry players and research groups as well as collaborations with local governments have been decisive for mobilising both human and financial capital in the system. Although the national culture has negative impact on individual's attitudes towards self-employment, it promotes innovation and entrepreneurship in the NIS. Moreover, the fact that Norway is low power distance country (Hofstede, 1991) means that the Norwegian organisational culture (and industrial) has great potential in creating environment that stimulates innovation. Power distance reveals power and hierarchical relationships in a country (Hofstede, 2001). It uncovers society's acceptance of power and inequality. Large power distance countries are characterised by formal and centralised organisational structures while decentralisation of decisions making and flat organisational structures are common in small power distance countries such as Norway (ibid). Ultimately, small power distance countries display collaboration and communication across all structures of the organisation, making it possible to exchange information, promote and encourage innovation and creativities (Hofstede, 1991). The Norwegian organisational culture is driven by teamwork, and many people are involved in the decision-making process. These arguments are well supported by remarks from Ole Grimsrud, the R&D Vice President of Scatec AS and Alf Bjørseth, the Founder of NorSun and Scatec AS. In the interview conversation with Grimsrud, he described the cultural aspect of innovation in the PV industry:

"Norway has an advantage when it comes to the implementation of new technology developed in a lab. In the first factories in Glomfjord, there were operators, who did a lot of work manually before the automation of production. In other countries, it would be natural to go to the engineers in the office, behind the desk and draw a file in InDesign, without talking to those on the floor. While in Norway, it was done completely in a different way. It was in fact, those who worked manually, which gave input on how it should be done automatically. I think it is an advantage that Norway has; and it is not only in solar industry." (Ole Grimsrud, Empirical Interview 29.11.12)

The function "knowledge development and diffusion" will show that this type of organisational culture was decisive in the creation of production knowledge during the initial phase of the system (see section 5.3.1.2). Bjørseth stressed that this type of innovation milieu requires "that you have a relationship, and that the hierarchy is not very strongly developed" and the fact that "anyone in the organisation can speak to anyone worked very well for us" (Bjørseth , 2012). This type of milieu encourages trust not only within the organisation, but also outside of the organisation, when collaborating with partners. This is also consistent with Hofstede's second cultural dimension, Uncertainty Avoidance Index (UAI) which explains whether a culture is threatened by uncertainties or unknown situations (Hofstede, 1991, p. 113). In low (moderate) UIA countries such as Norway (ibid), employees are less depended on rules and there is room for trust between employees and partners. Grimsrud (2012) mentioned that "the fact that everyone knows everyone else" is an advantage in Norway makes it "safer for us" to collaborate with the Research Institute in Norway, because "we are quite confident that IP will not leak out". This is also well illustrated in the nature of collaboration in research networks such as Solar United and FFF. Essentially, the level of uncertainty profoundly affects the organisation and management of institutions (Hofstede, 1980). In Norway, the organisation and management of the

R&D activities is mainly organised in collaborations between research institutes and industry players. In a way, the national context (or NIS) has created a learning environment for the Norwegian PV TIS by stimulating information flow and knowledge exchange between actors. Ultimately, industrial culture in the Norwegian PV TIS is characterised by informal business attitudes with high level of collaboration, and people are more receptive of change:

"There was a lot of innovation in the borderland between REC, ScanWafer and suppliers such as Tronrud, Prediktor. There were relatively small suppliers who were willing to take considerable risks in developing things with REC and ScanWafer." (Ole Grimsrud, Empirical Interview 29.11.12)

This quote indicates that there is high willingness of collaboration between actors within the system, and that actors are willing to take risks. This is well reflected in the functions "Influence on the direction of search" and "entrepreneurial experimentation" when private investors guided the direction of the search by allocating financial resources into the system. Moreover, section 5.3.1 will reveal that both industry and research players collaborate in joint research platform through The Norwegian Research Centre of Solar Cell Technology in order to strengthen the development of the Norwegian PV TIS. These types of interactions are possible, because the cultural framework induces diversities, learning and interactions between actors, which in turn contribute to "knowledge development and diffusion" and "entrepreneurial experimentation". Recalling from the former section, actors within the Norwegian PV TIS interact in both formal and informal networks through R&D based networks, strategic collaborations and educational networks in order respond to industry trends, increase the dynamic of learning and exchange knowledge. Given the dynamic of collaboration in the Norwegian PV TIS, it is evident that actors are not only influenced by organisational culture, but also by national values.

5.3 THE FUNCTIONAL ANALYSIS OF THE NORWEGIAN PV TIS

Although the functions are drivers of the TIS, a combination of structural and functional analysis is essential for identifying blocking and inducement mechanisms. This is especially essential for understanding the processes under which the institutional infrastructure influences the allocation of resources in the Norwegian PV TIS. In addition, a functional analysis opens the space to look inside the system, and analyse the performance of different innovation processes. This focus can help determine the performance of a particular function. Having described the structures of the Norwegian PV TIS in the previous section, this section provides a functional analysis of the system reviewed in section 4.5.3. In order to understand the performance of the Norwegian PV TIS, an attempt is made to analyse the functional pattern as well as overall dynamic and goal. First, the functions are assessed, and the strengths and weaknesses of each function are evaluated. Second, the system goals of the functions of the Norwegian PV TIS are defined on the basis of the three methods mentioned in section 4.5.4: (i) establish what phase the TIS and (i), (ii) comparing TIS in other locations and (iii) assessing actors' attitudes toward the system.

5.3.1 KNOWLEDGE DEVELOPMENT AND DIFFUSION

Knowledge is perquisite to innovation processes, and a significant element for the evolution of TIS. It captures the breath and death of the knowledge base of the TIS, and how well is diffused and combined in the system (Bergek, et al., 2008a). This function is related to "Learning", which is the most important process in a modern economy (Lundvall, 1992). In other words, there is distinction between different types of knowledge (such as production, technological, design, market and scientific knowledge) and different sources of knowledge development (Bergek, et al., 2008a). The source of Knowledge does not only include R&D activities, but also knowledge produced through "learning by doing" and "learning by searching" (Bergek, et al., 2008a; Lundvall, 1992; Johnson, 1992). For learning to occur at the system level, knowledge diffusion needs to take place through "learning by using" and "Learning by interacting". For example, during the initial stage of the PV system in Germany, knowledge base was emerging from R&D activities, and the type of knowledge development was limited to technological and scientific knowledge (Jacobsson & Bergek , 2004). Eventually, the knowledge based was broadened as activities were expanded along the entire value chain. Scientific knowledge was produced, because of R&D activities taking place in universities and research institutes led to application of knowledge in downstream activities. Later, upstream knowledge were developed through R&D activities (ibid).

In the case of the Norwegian TIS, Hanson (2008) distinguishes between three phases of innovation in the Norwegian PV industry: (i) a pre-production phase characterised by explorative activities and learning process, (ii) an establishment phase characterized by incremental innovation processes provided by the prime movers and (iii) a momentum phase characterised by increased demand and competition for more efficient mono-crystalline silicon, which lead to the creation of variety. In addition to the aforementioned phases, a fourth innovation phase is introduced, namely (iv) the assessment phase. This phase is characterised by expansion of downstream activities and new technologies. These phases[27] are interconnected, and the types of knowledge developed during these cycles are differentiated by experience-based, technological, production, market and application

[27] These phases refer to the phases of function "knowledge development and diffusion", and are not to be confused with the overall phase of the Norwegian PV TIS.

knowledge. In addition, the different types of knowledge were developed through "learning by searching", "learning by doing", "learning by interacting" and "learning by using.

In this section, the author of this these have argued that the knowledge base of the Norwegian PV TIS is a conglomerate of several types of knowledge developed through different types of knowledge sources at the different phases of the knowledge development. It is thus somewhat practical to map the knowledge dynamic occurring at the different phases of F1

5.3.1.1 THE PRE-PRODUCTION PHASE: SEARCHING AND CAPTURING KNOWLEDGE

Since knowledge is a process of change, it is subject to variation, selection and retention (McKelvey , 1997). The mechanisms of variation, selection and retention are used here to conceptualise the development of knowledge during the different phases. These three mechanisms are the core of knowledge development, and shows that innovation is an evolutionary process in which, knowledge is varied, selected and retained. As this section will show, during the pre-production phase, Elkem went through several processes in order to adapt to external changes and create variety through explorative varieties. In other words, by continually exploring new areas, Elkem generated new knowledge, and in so doing, the ability of understanding the technological knowledge of silicon production was increased.

❖ **Experience-based knowledge: Developing and Acquiring Expertise**

Although, the Norwegian PV TIS is relatively new, Norway has over the years acquired substantial amount of expertise involving material sciences and silicon processing through *learning by searching* and *learning by doing*. During the last century, Elkem has managed to develop strong and broad knowledge in furnace technology and refining of metals, especially in the production of silicon (Kaus, 2012; Grimsrud, 2012; Tronstad, 2012; Klitkou & Coenen , 2013). The company's historical explorative learning processes created new knowledge, and transform the learning dynamics between incumbent and novel technologies. These historical experiences were fundamental for the development of the Norwegian PV TIS (Klitkou & Coenen , 2013; Hanson, 2008; Tronstad, 2012). It is difficult to provide a detailed examination of all knowledge accumulated during the pre-production phase of the system, because it spans over period of a century. However, an attempt is made to capture the momentums that are relevant for this thesis.

Since its foundation in 1904, Elkem was involved in the development of electrometallurgical processes (Tronstad, 2012; Klitkou & Coenen , 2013; Christiansen & Buen, 2002). Later, the company explored new activities involving the development of furnaces and the production of silicon. Subsequently, industrial knowledge in silicon production was developed. After the Second World War, the company started exploring activities for the production of aluminium and ferroalloy (Christiansen & Buen, 2002; Tronstad, 2012). With the new direction, Elkem focused on building expertise in metallurgical grade as well as exploring ways of producing silicon in cost effective and energy efficient manner (Tronstad, 2012). All throughout 1960s toward 1970s, the company continued to expand internationally, and explored activities in the production of energy efficient silicon, through its production of metallurgical grade silicon to the world market (ibid). According to some of the informants, activities toward PV technology started already in 1980s (Tronstad, 2012; Mühlbradt , 2012; Grimsrud, 2012). Although, Elkem was in the business of producing silicon, the quality was "not sufficient to use in solar cells" (Tronstad, 2012). Subsequently, "l*earning by doing"* and theoretical studies led to experience-based knowledge, in which the company improved the quality of purification process towards solar grade silicon (ibid). Through *"learning by doing"* Elkem became more practiced and thus more competent at "activities in which it is already engaged" (Cohen & Levinthal, 1990).

Although "*learning by doing*" does not essentially create the diversity needed to create new knowledge (ibid), having developed competence in one area might increase a firm's ability to assess new opportunities. In this case, Elkem recognised that melting furnace was central for the production of silicon, and took the direction for searching (*learning by searching*) for new expertise (Hanson, 2008; Tronstad, 2012). In doing so, Elkem invested in R&D activities in order to increase its science-based knowledge (ibid). These two types of knowledge development (experience-based and science-based knowledge) were vital for Elkem's strategic choice leading to the creation of new knowledge. In addition to experience-based and science-based knowledge, the company explored metallurgical knowledge both in the production, characterisation of silicon and ferroalloy through mergers and acquisitions. At this point, the company's vision was clear: To produce cost efficient silicon for solar cells with higher purity and low energy (Tronstad, 2012). As such, the process of *"Learning by searching"* started by capturing new technologies and solutions that would challenge efficient and cost effective production process of silicon for PV cells. This search led to the acquisitions of the British company Crystalox in 1980, a producer of crystallisation ovens for the production of ingots and Union Crucible's ferroalloy operation in the 1980s (Tronstad, 2012; Ruud & Larsen, 2005; Klitkou, 2010).

Since firms with in-house R&D are better positioned in internalising external knowledge (Cohen & Levinthal, 1990), laboratories experiments through Elkem Research were also a part of the searching process. In order to supplement the internal scientific knowledge developed in Elkem Research and the crystallisation technology, the company began a process of *"learning through interaction"* with universities and research institutes (Tronstad, 2012). Elkem's strategy toward knowledge development shows that exploring external knowledge is critical to innovative capabilities (Cohen & Levinthal, 1990), and that organisational knowledge is significant for innovation process.

❖ **Market Knowledge: Market pull & technology Push strategies**

Traditionally, "Elkem provided metallurgical grade silicon to customers", and developed "knowledge for the production of standard silicon" and "networks in the PV industry" (Tronstad, 2012). Darroch & McNaughton (2002) mentioned that innovative companies need both market pull and technology-push strategies, in that they should gain market knowledge from existing market, while at same time, create new knowledge with competitive advantage. Elkem has shown that direct involvement in manufacturing processes (Cohen & Levinthal, 1990) and interactions with customers are essential in creating new knowledge. With these expertise, Elkem started wafer related activities for the production of solar cells in the 90's (Tronstad, 2012). However, due to financial difficulties, all projects were terminated, and solar activities did not take off as planned (Tronstad, 2012; Ruud & Larsen, 2005).

Elkem's strategy concerning knowledge development and management can be viewed as a continuous process of learning, searching and capturing relevant knowledge. In fact, the company's innovation strategy was based on cumulative processes in which knowledge was the building block. Knowledge was developed through various learning processes, where new processes were explored in order to respond to future demands. This process is characterised by explorative activities through "*learning by doing*", "*learning by searching*" and "*learning by interacting*" during, which core competence in silicon, furnaces, metallurgical and material processes were developed. Although, Elkem did produce silicon cell during this phase of the knowledge process (Tronstad, 2012; Hanson, 2008), the technological knowledge in crystallisation and the knowledge of producing cost efficient silicon cells combined with experience-based and market knowledge laid the foundation of the next phase of the knowledge development (Grimsrud, 2012; Tronstad, 2012; Moen, 2012).

5.3.1.2 ESTABLISHMENT PHASE: ASSIMILATION AND THE CREATION OF KNOWLEDGE

Continuing on the thoughts of McKelvey (1997), the first mechanism involves the creation of variation, which generates more options during the selection process. The variation mechanism modifies the good solutions to generate new alternatives. Similarly, during the period of 1990s to 2001, production knowledge was created through the exploitation of the expertise developed in the Elkem's milieu. During this phase, the application of new knowledge and the learning capacity of actors were based on the stock of knowledge and experience that were acquired in Elkem's milieu. As illustrated in section 5.3.2, change in institutional set-up in the mid-1990s led to a process of knowledge transfer from established technology to novel technology. It allowed actors to create new knowledge through the exploitation of existing technological expertise (from Elkem milieu). In the words of one informant:

"The important aspect for focusing on PV in Norway was that there were many research groups, who previously worked in other fields, who saw that their expertise could be relevant for PV technology, and many of them direct their research activities towards PV" (Ole Grimsrud, Empirical Interview 29.11.12)

Following on the above statement, industrial knowledge from existing workforce (Hanson, 2008) was relevant during the first production process of ScanWafer in Glomfjord. Here, Grimsrud is referring to the research willingness of actors during the initial stage of the system. Through the silicon and aluminium industries, Norway developed competitive advantage in the processing of metallurgical silicon and knowledge within material science such as crystallisation and characterisation activities. The combinations of all these expertise and competence are relevant for the development of PV technology, and were thus transferred into to the Norwegian PV TIS. For instance, Bjørseth, the main entrepreneur behind the establishment of the Norwegian PV industry (see section: 5.3.3) employed some of his colleagues from Elkem (Klitkou, 2010; Ruud & Larsen, 2005). Here, institutional set-up was aligned to serve the new technology, thus allowing the transfer of knowledge between incumbent and novel technology.

In addition, the tacit knowledge from Dr David Hukin and Dr Daniele Margadonna were crucial during the establishment of the first factories in Glomfjord. David Hukin was founder of Crystalox, and had particularly knowledge in the crystallisation aspect of the production (Ruud & Larsen, 2005). Daniele Margadonna was a technical director for Eurosolare, an Italian manufacturing of solar cell panels, and was responsible for the development of sawing ingots blocks to wafers (ibid). The combinations of these types of technological knowledge have shown to be vital during the first production facility of ScanWafer in Glomfjord. At this point, two leaning processes took place. First, when Dr Margadonna and Dr Hukin articulated the substance of their tacit knowledge of crystallisation and sawing technologies, they converted it into explicit knowledge, allowing it to be shared with the rest of the company. Second, combining these types of technological knowledge has explicitly created new knowledge.

Although, the creation of variety is essential for the knowledge base of the system, ultimately, the creation of knowledge depends on the research willingness of actors (Jacobsson & Johnson, 2000). Scientific and technological knowledge were hence essential ingredients during the early years of the system. However, the role of universities and research institutes has been different for the establishment of each PV firms. The main perceptions from most informants are that the university and research environment did not play major roles during the earlier years of the system (Tronstad, 2012; Grimsrud, 2012; Mühlbradt , 2012; Moen, 2012). Elkem's background on silicon processing and production, ownership in Crystalox, the establishment of ScanWafer and REC are the factors that laid the foundation for the scientific knowledge during the initial stage of the system. Additionally, the research background of the actors involved in the first productions in Glomfjord combined with practical knowledge of the workforce from existing technologies and the financial resources as well as access to infrastructure (see section: 5.3.6) were somewhat vital for learning process and knowledge development. Since the production of both pure silicon and wafers is energy-intensive process, which can lead to negative impact on the environment (Ruud & Larsen, 2005), taking advantage of the Norwegian hydroelectric power and other resources were essential during the production process. Evidently, ScanWafer recognised that achieving competitive advantage required efficient use of material and production optimisation (Grimsrud, 2012; Ruud & Larsen, 2005).

The goal was to improve existing products available in the market at lower cost (Grimsrud, 2012; Ruud & Larsen, 2005). Subsequently, several processes of *"learning by searching"* and *"learning by interaction"* were launched, during which technological expertise was fundamental. At this point, technological diffusion took place when actors within the supply market and users interacted with each other (Stoneman & Diederen, 1994). Lundvall mentions, "one way to illustrate how the structure of production and the institutional set-up, together, affect the rate and direction of innovation is to focus upon the product innovation and their roots in the interaction between producers and users" (Lundvall, 1992, p.10). In other words, the structures of production define the set of user-producer relationship at the micro level. Such was the case of German wind turbines, in which manufacturer competence was developed in collaboration with users through learning-by-doing and learning-by-using (Jacobsson & Johnson, 2000). In the case of the Norwegian PV TIS, production and technological knowledge were produced through interactions and searching with both national and international companies. For instance, Several processes of production and technological innovations involving collaborations with ALD Vacuum Technologies AG concerning melting furnace and crystallisation technologies combined with sawing technologies from HCT, and production automation developed in collaboration with Tronrud Engineering and Prediktor lead to radical innovation in the production process (Ruud & Larsen, 2005; Hanson, 2008; Pettersen, 2013).

In 2003, Scan Wafer collaborated with the German company, ALD Vacuum Technologies AG (Ruud & Larsen, 2005; Bjørseth , 2012; Hanson, 2008; Klitkou, 2010) for a long-term agreement for the purchase of stoves. The purpose of the collaboration was to improve the efficiency of the crystallization furnaces. In the agreement, ALD received an equity portion of ScanWafer as a part of the payment (Klitkou, 2010; Ruud & Larsen, 2005). In addition, ScanWafer received ten years of exclusive rights for usage of the technology, in return for buying an agreed amount of furnaces (ibid). During this process of *"user-producer interaction",* the two companies did not only exchange assets, but they also produced a crystallisation technology that was essential for Scanwafer's competitive advantage. In addition, employees collaborated with the Swiss company HCT in designing specialized type of saw for which ScanWafer now owns exclusive rights (Ruud & Larsen, 2005; Hanson, 2008). As mentioned in section 5.2.3.2, the flat organisation culture created the environment and induce innovation at all part of the company. Hanson (2009) classified the production process as an incremental innovation. However, one of the informants mentioned that:

> During the period of REC, we worked in Glomfjord, a small village in northern Norway with 1500 inhabitants. We had to automate the production, and improve the crystallization process, because there were not enough workforces when we decided to increase production. Consequently, we collaborated with Tronrud Engineering and a German company in order to automate the production line, and improve the crystallisation process. We were the world's first automated PV production line and REC is still the only company that owns this type of technology. These have been radical improvements in the production technology (Alf Bjørseth, Empirical Interview 29.11.12)

The introduction of the aforementioned technologies automated the operations and the production processes, which in turn contributed to cost reduction. The above statement is also consistent with Ruud and Larsen (2005) who noted that the "The crystallisation furnace was technically the biggest innovation for ScanWafer". It shows that the combinations between scientific and production knowledge were crucial for reducing cost. Improvements in production can lead to reduction in production cost and increase profits (Stoneman & Diederen , 1994). Essentially, the profits generated in the first part of the diffusion process are reinvested in R&D to improve the technological and production knowledge (ibid). Similarly, ScanWafer had taken advantage of the automation of production processes from the automotive industry (Bjørseth , 2012) in order to achieve economic of scale. As a result, the thickness of the wafers produced reduced from 330 micrometres in the first two production facilities to 180 micrometres in the fourth production facility (Klitkou, 2010). This shows that the formation of new networks can be central to the process of fostering variety (Jacobsson & Johnson, 2000). During this learning process, existing knowledge were preserved, and new external knowledge were absorbed and internalised through the interaction with users and producers. Learning took place when knowledge was used, and it improved the stock of knowledge available in the system (Darroch & McNaughton , 2002). Consequently, upstream knowledge was created through the interaction between tacit and explicit knowledge, and several actors entered different part of the upstream part of the value chain.

5.3.1.3 MOMENTUM PHASE: STRENGTHENING UPSTREAM KNOWLEDGE

Diffusion process is characterised by increasing numbers of companies owning and using technology (Stoneman & Diederen , 1994). Essentially, a selection process takes place, in which the worst solutions are eliminated and the better ones are replicated. However, choices made during the selection of competences (or technology) are affected by both internal and external factors. In the case of the Norwegian PV TIS, selection was influenced by access to raw material, cost, market demand as well as technological competence of actors.

First, during the period between late 1990s and 2007, access to raw materials was significant in responding to demand (F3) and securing production (F1) (Bjørseth , 2012; Hanson, 2008; Ruud & Larsen, 2005). Actors' response to these threats involved the allocation of resources and knowledge through strategic alliances, merges and acquisitions in vertically integrated cluster of ownership structure, which covered all part of the value chain[28] (Christiansen & Buen, 2002). For instance, ScanWafer collaborated with Elkem through a jointly owned company, Solar Silicon AS, which was developing a new process in securing raw material (Klitkou, 2010; Ruud & Larsen, 2005). As a part of the agreement, both parties were to inform each other about rival projects. Nevertheless, Elkem had a secret collaboration with AstroPower, and ScanWafer terminated its technical collaboration with the company (Ruud & Larsen, 2005). Essentially, the acquisition of Solar Grade Silicon secured access to

[28] These include production of solar-grade silicon (Silicon Technologies, in a joint-venture with the US company ASiMi), wafer production (SW), PV cell production (ScanCell), PV cell module production (ScanModule) as well as installation and operation (SolEnergy), the umbrella companies of Renewable Energy Corporation (REC). (Christiansen & Buen, 2002) Similar structure is present in other part of the industry. Scatec: production monocrystalline silicon (NorSun), installation of turnkey system (Scatec Solar), selling power (Scatec Power).

raw material. Similarly, NorSun collaborated with Elkem Solar, when access to polysilicon was essential in responding to its international demand[29] (Klitkou, 2010).

Second, there was demand for increased efficiency in silicon solar cells. At this point, upstream technologies were improved and selection process took place. From the beginning of 2000, the focus was to strengthen and improve existing upstream knowledge. While "*knowledge development*" was mainly based on "off the shelf" equipment during the previous phase, (Christiansen & Buen, 2002), R&D was essential in strengthening systems knowledge and competence during the momentum phase. Similarly, Hanson (2008) mentioned that the selection of the production method depended on learning processes and knowledge base of the system. At this stage, the basic research activities concerning the creation of new solar silicon processes and material processing are developed in collaboration with both Norwegian and foreign research institutes and universities, while the product applications, technical and ingot production processes were developed in-house. As results, actors within the Norwegian PV TIS have built a substantial amount of scientific knowledge concerning silicon production, crystallisation and characterisation processes, material science and processes as well as other scientific expertise relevant for PV technology.

There is a large research community both in the majors companies, the universities and research institutes. Both industry and research actors are preoccupied with maintaining Norway's competitive advantage in the production of silicon cells and crystallisation processes, while at the same time exploring new technological areas leading to cost reduction and efficiency. This trend is well reflected in the R&D activities across the system. As shown in table 5.1, most R&D activities emphasise on improving the silicon material for the production of solar cell, understanding the silicon production processes, developing material for highly efficient PV cells, developing next generation solar cells and developing efficient solutions for solar parks. For instance, Both SINTEF and NTNU[30] are important players in the research environment, focusing on the development of new processes in the production of Silicon feedstock, solidification of Si ingots, wafer sawing technology and material characterization (Foss, 2012; Juel , 2012; Kaus, 2012; Bugge, 2012). The Centre for Materials Science Nanotechnology (SMN) in the Faculty of Mathematics and Natural Sciences at UiO is also involved in the R&D activities (Bugge, 2012). The centre has competence and expertise in the field of semiconductor

[29] NorSun was initially buying fixed annual volumes of polysilicon from SunPower Corporation at fixed prices. The deal did not cover all the needs of NorSun, hence the collaboration with Elkem Solar (Klitkou, 2010).
[30] NTNU is also involved in third generation solar cell.

physics, Si-components, materials chemistry, theory and modelling. IFE[31] is another important player, focusing on silicon solar cell design, production and characterization and research on the effect of material quality upon solar cell performance (Foss, 2012; Bugge, 2012). In addition, UiA is also involved in theoretical studies of concepts such as tandem cells, intermediate band gap cells and spectrum splitting schemes and system modelling (Bugge, 2012)[32]. Activities in this programme include PV module testing and lifetime assessment, statistical PV system performance analysis, understanding PV system operation through modeling and understanding effects related to new technologies (Bugge, 2012; Imenes , 2012). Other relevant research actors include Teknova, which is involved in the optimization of glass properties and thin coatings used in solar cell panels, and the end use of solar cell technology in Norway (Bugge, 2012; Imenes , 2012).

Table 5.1: R&D activities in the Norwegian PV innovation system

Units	R&D Activities	Actors
Metallurgy department within Materials & Chemistry division	✓ Development of new processes in the production of Silicon feedstock ✓ Casting and solidification of Si ingots ✓ Wafer sawing technology ✓ Material characterization ✓ Crystallisation of solar cell silicon & defect Engineering	**SINTEF**
Energy Conversion and Materials department within Materials & Chemistry division	✓ Si production by electrolysis ✓ Si wafer processing and development, ✓ 3rd generation technology ✓ Nanomaterial and thin film technologies	**SINTEF**
The Solar Energy department	✓ Production of solar grade silicon - processes of multi- and monocrystalline silicon wafers ✓ Development of novel silicon solar cell structures incorporating various functional thin films. ✓ Characterization of solar cells ✓ Silicon solar cell design ✓ Research on the effect of material quality upon solar cell performance and efficiency	**IFE**

31 The IFE Solar Cell Laboratory carries out R&D production activities for processing multi- and monocrystalline silicon wafers. These activities include all the necessary equipment required for converting crystalline silicon wafers into solar cells. Examples of R&D projects include research on modeling of diffusion, development of novel silicon solar cell structures incorporating various functional thin films. IFE Solar Cell Laboratory contains equipment for depositing thin film materials. A characterisation laboratory is also accessible, containing instruments for characterizing solar cells, solar modules and solar cell materials (Bugge, 2012 (Foss, 2012)).

32 The university has an outdoor test station for I-V curve measurements of PV modules and laboratories for development of PV technology (Imenes , 2012 (Bugge, 2012)).

Department of Materials Science and Engineering within the Faculty of Material Sciences & Technology	✓ Materials characterization, ✓ Casting and solidification of aluminium and solar cell silicon ✓ Nanostructuring & Material technology	**NTNU**
Department of Physics within the Faculty of Material Sciences & Technology	✓ Nanomaterials for 3rd Generation Solar Cells ✓ New solar cell Nano-materials ✓ Multicrystalline silicon solar cell material ✓ Intermediate band solar cell materials	**NTNU**
The Norwegian Research Centre for Solar Cell Technology	✓ Mono- and multi-crystalline silicon ✓ Next-generation modelling tools for crystallizing silicon ✓ Solar cell and solar panel technology ✓ New materials for next-generation solar cells ✓ New characterization methods	**IFE, SINTEF, UiO, Elkem, NorSun, REC, Fesil Sunergy, NTNU, Quartz Corp**
Centre for Materials Science and Nanotechnology - MiNaLab	✓ Semiconductor process technology, ✓ Characterization and photovoltaics - emphasis on new materials for solar cells ✓ Semiconductor Nano science/technology	**University of Oslo**
Faculty of Engineering sciences	✓ Spectrum splitting schemes ✓ System modeling ✓ Test station for I-V curve measurements of PV modules ✓ Electromagnetic modeling and design ✓ Degradation of solar silicon, ✓ Third-generation concepts and ✓ Tandem cells concepts ✓ Intermediate band gap cells	**UiA**
Renewable Technologies and Material Technology Groups	✓ Solar Energy Systems: Control, optimization and cold climate adaptation ✓ Simulation of solar system ✓ Characterization of solar cells materials ✓ Surface treatment and thin film techniques ✓ Simulation of silicon casting ✓ Recycling of silicon and quartz ✓ Energy supply for buildings	**NORUT**
Measurement Technology, Process technology and Renewable technology	✓ Degradation of the solar cell material under environmental stress ✓ Process Technology ✓ Optimization of glass properties and thin coatings used in solar cell panels ✓ End use of solar cell technology ✓ Measurement Technology ✓ The use of renewable energy in buildings ✓ Measurement and optimization of energy flow ✓ Energy storage and grid integration	**Teknova, Elkem**

In addition, through the Norwegian Research Centres for Solar Cell Technology, the system has mobilised the competence and knowledge of all major research groups and industry players in order to improve existing knowledge as well as developing new technologies (Solar United , 2012). The centre emphasises on six research areas, which involve competence- building in mono- and multicrystalline silicon, next-generation modelling tools for crystallizing silicon, solar cell and solar panel technology, new materials for next-generation solar cells, and new characterization methods as well as value-chain demonstration projects (Solar United , 2012; Bugge, 2012; Foss, 2012; Juel , 2012; Kaus, 2012; Tranell, 2012).

During the momentum phase, the entering of new firms and the alignment of the research groups led to the improvement of scientific and technology knowledge. Upstream technologies were selected based on the technological expertise of prime movers. In this phase, existing technologies were exploited through increased interactions between both national and international research environment. In addition, the entrance of new players enhanced the knowledge based of the system, in which upstream activities became the core competence. During this process, the competences of the actors are transformed into collective knowledge through research collaborations and partnerships, which in turn expanded the network dynamic of the system.

5.3.1.4 THE ASSESSMENT PHASE: DEVELOPING DOWNSTREAM AND NEW KNOWLEDGE

During the momentum phase, the process of variation and selection seems to be interdependent, in which upstream production activities are reproduced and improved by different actors. At this point, a retention process led to increase dynamics of networking and collective R&D programs between industry, research and supplying actors[33]. In the assessment phase, retention seems to depend on learning and sharing among actors. Consequently, at the system level, retention preserves the technological and the scientific knowledge of all actors, collectively, to exploit the resources of their environments and to solve future problems. During this phase, the knowledge base of the system is expanded across all part of the value chain. In addition, existing knowledge are being exploited in order to create third generation technologies.

This phase is characterised by turbulence periods of economic crisis leading to low demand and competition from low cost countries such as China, driving down price and increasing competition in the international market (see section 5.3.2). Although these conditions have great impact on the Norwegian actors operating in the upstream part of the value, low prices in PV cell represent great opportunities for downstream players such as Scatec Power, Getek, Scatec Solar and ITS. Essentially, these actors are strengthening their downstream knowledge in order to compete at the international market. As such, the knowledge base of the system is being expanded to include all part of the value

[33] For example, the Norwegian Research Centre of Solar Technologies

chain. Project management skills and financial expertise have been essential ingredients in remaining competitive (Osmundsen , 2012). First, the fact that the offshore sector in Norway has built good expertise in project management means that there has been a process of knowledge transfer from incumbent technologies such as oil and gas into downstream-related activities (ibid). For instance, in regards to project management, the downstream players have mobilised human resources from the oil and gas industries (Osmundsen , 2012; Nilsen, 2012; Tuv, 2013). Second, in regards to financial expertise, there is a cluster around GIEK, Export Finans, financial institutions and private banks such as DnB (Osmundsen , 2012). Partnerships with these communities have allowed downstream players to learn, and develop financial expertise in project management (ibid).

In addition, new knowledge is being implemented at different part of the value chain as research players and some industry actors as well as new players are in the process of developing knowledge for third generation technologies (see section 5.3.3). Actors are concerned with developing new concepts, which would increase the efficiency of PV cells, and compete with products in the existing market. Nanocrystal technology based on optical absorption of metal nanoparticles is an example of what is being developed by new entrants. The department of Physics in NTNU is also involved in the development of solar cells based on thin films and quantum structures.

- **Strengths and Weaknesses of the Function "Knowledge Development & Diffusion"**

The knowledge base of the system illustrates a great example of evolutionary process of knowledge development. During a short period, actors within the Norwegian PV TIS have developed a substantial amount of knowledge and expertise within upstream activities. First, from 1900s to 1990s, Elkem created new knowledge through several processes of *"searching and capturing"* cumulative competence in order to create new knowledge (products) for a new market. Essentially, learning took place through user-producers interactions and the acquisitions of relevant technologies, supplemented by both internal and external R&D activities. Second, prime movers such as ScanWafer were able to accumulate, use and exploit knowledge developed over a century in order to serve demand from a new market. By doing so, scientific and technological knowledge were created through user-producer interactions. This illustrates actors' ability to understand market trends as well as learning capacity to build competitive advantage. Third, during the momentum phase, the research groups were aligned to serve the new TIS. Consequently, upstream activities were strengthened, and the dynamic of interactive learning was improved through R&D collaborations, strategic alliances and international networks. The knowledge base was expanded as new players entered the system. Fourth, during the assessment phase (turbulence time), the collective knowledge of the system is being mobilised in order to improve existing technologies, and to develop new competitive knowledge. Subsequently, midstream and downstream knowledge are starting to appear in the system.

5.3.2 INFLUENCE ON THE DIRECTION OF SEARCH

While the first function deals with the creation of knowledge and its diffusion, the second function influences the directions in which actors deploy their resources (Bergek & Jacobsson , 2003). Jacobsson and Bergek (2011) mentioned that the function is related to institutional factors and guidance in regards to technological choice (Bergek & Jacobsson , 2003). It represents the selection process that is needed to accelerate development (Suurs & Hekkert, 2009). This function refers to those activities within the system that can positively influence specific desires among technology users (Hekkert , et al., 2007). It also deals with actors' attitudes toward the TIS in terms of growth potential, in relation with providing legitimacy for the new TIS (Bergek & Jacobsson , 2003). Actors are normally guided by factors such as incentive structures, expectations (Jacobsson & Bergek, 2011), belief in growth potential, regulatory pressures, changes in landscape and articulation of demand (Bergek, et al., 2008a). One example is Norway's target of 67.5 percent renewable energy by 2020 in the EEA Agreement of Renewable Energy Directive mentioned in section 5.2.3.1.

As illustrated in the case of the wind turbines in Germany, government incentives combined with changes in landscape motivated several players to enter the industry (Bergek & Jacobsson , 2003). During this period, existing markets were in recession, Californian wind turbine was growing and Danish wind turbine industry was expanding. These changes as well as demand from utilities and environmentally concerned farmers created opportunities and expectations for future turbine market. This function shows that societal changes can influence R&D priorities and the direction of technological change (Hekkert , et al., 2007). In other words, shaping the selection environment is essential for system development. In the case of the Norwegian PV TIS, during the period 1970s – 1990s, several landscape changes led to the promotion of R&D funding for PV activities. Although, there were no policies promoting the use of PV technology during the aforementioned period, there have been some public R&D schemes supporting collaboration between industry and research institutes on the development of PV technology (Christiansen & Buen, 2002; Klitkou & Godø , 2010). These programmes were initiated subsequent to the oil crisis of 1973, and involved the development of renewable energy such as wave, bio and solar technologies (Klitkou & Godø , 2010). Subsequently, in 1979, The Ministry of Petroleum and Energy mobilised PV research activities in Norway under a working group[34] (WP), namely SOLKOM (Christiansen & Buen, 2002). The purpose was for the WP to coordinate PV research activities in research institutions, universities and companies (ibid). Therefore, public funding was established in the early 1980s in order to support activities concerning separation techniques and production of metallurgical-grade silicon. These actions indicated that policy makers were attempting to assure the effective use of resources by influencing the search of new knowledge in a specific direction. Jacobsson and Johnson (2000) mentioned that these type policy measures could facilitate the improvement of relationships between institutions and actors and the diffusion of new knowledge.

However, within the Norwegian PV TIS, several changes in the landscape led to negative feedback loop in the system. As energy prices fell in 1980, actors' interests in PV technologies disappeared (Christiansen & Buen, 2002). Subsequently, the level of public funding for renewable technologies gradually diminished during the 1980s and the first half of 1990s (Klitkou & Godø , 2010), and there were limited research of PV technology at the Norwegian Institute of Technology (NTH) (Christiansen & Buen, 2002). At the same time, the Norwegian Parliament had prioritised funding of R&D on material technology, and public support of research on photovoltaic energy came back on the agenda at the end of the 1980s (Klitkou & Godø , 2010). Although Norway was a large producer of silicon through companies such as Elkem and Fesil, it lacked the competence for developing silicon for collar cells. A Solar energy programme, funded by The NTNF and the Ministry of Petroleum and Energy (OED), was initiated between 1989 and 1994 (Christiansen & Buen, 2002; Klitkou & Godø , 2010). Still at this point, the program had more focus on solar thermal energy, and funding of solar PV was only marginal. Elkem was at the time, one the few actors exploiting opportunities in the PV market. However, due to the economic crisis at the beginning of the 90's, Elkem made a strategic decision for not pursuing activities involving wafer production (Ruud & Larsen, 2005; Hanson, 2008; Tronstad, 2012). This period shows that lack of governmental initiatives and prime movers as well as unfavourable external conditions created negative loop, and hampered the development and the direction of the Norwegian PV TIS.

Despite Norway's competitive advantage of cheap electricity and abundance of cooling water, and the fact that the country was producing 25 per cent of the world's metallurgical silicon[35] (Christiansen & Buen, 2002), interests in PV technologies did not occur before late 70's and early 1980s. According to

[34] A working group was set up under The Royal Norwegian Council for Scientific and Industrial Research (NTNF) (Christiansen & Buen, 2002).
[35] According to Christiansen & Buen (2002), Fesil and Elkem controlled 25 percent of world's production. They served around 50 per cent of the global market for metallurgical silicon for the semiconductor industry.

Christiansen and Buen (2002), the success of emerging technologies is highly depended on actors' capabilities of incorporating technological competence and problem solving skills into innovative strategies in exploiting of new business opportunities. At the same, since firms' learning processes are often path-dependent, their organisational learning habit makes them exploit new opportunities that are similar to their previous experiences (Jacobsson & Bergek, 2011). This path dependency was present during the establishment of ScanWafer, who was exploiting existing competence in creating new knowledge. During the period of 1990s to 2001, public subsidy programmes in other countries, resulting market formation (see sections 5.3.4 and 5.3.5) combined with actors' knowledge regarding wafer production guided the direction of search. Despite the unfavourable economic conditions, actors' belief in growth potential led to the creation of new knowledge. Actors' abilities to recognise market potential was mainly influenced by the increasing global demand for wafer due to favourable government incentives in European countries, especially in Germany, Spain and other countries such Japan. As such, the first entrepreneurial experimentations did not involve heavy R&D investments (Klitkou & Godø , 2010).

Normally, R&D programmes funded by the government, the capital goods industry and other incentives are vital during initial stage of a TIS (Bergek , et al., 2008b). As we have seen in the case of the Wind Power in Germany, during the period of 1977, governmental R&D programmes was awarded to 19 industrial firms and academic organisation for the development (and testing) of different varieties of wind technologies (Bergek & Jacobsson , 2003). Subsequently, these activities (experiments) stimulated the creation of variety, and attracted new firms into the system (ibid). The case of the German wind power indicates that policy decisions should support the emerging technology and, at the same time, R&D agendas should be influenced by changes in institutional structure (Bergek, et al., 2008a). However, in the case of the Norwegian PV TIS, during the period between 1990 and 2000 there were no policy instruments targeted at the development of the Norwegian PV TIS. Despite lack of governmental PV specific incentives, several regional policy instruments such as regional based investment funds and business development incubators as well as cooperation with the Norwegian Industrial and Regional Development Fund (SND), Nordlandsbanken and investment from Norsk Hydro guided the direction of search.

Since there were no governmental incentives motivating actors in entering the Norwegian PV TIS, the articulation of demand from customers was at this stage significant in attracting investors. SND was willing to provide investment equal to 25 percent of the total investment amount if ScanWafer managed to obtain bank loans, and if they could document a market for wafers (Klitkou, 2010; Ruud &

Larsen, 2005). Consequently, the company signed sales contracts with Neste Advanced Power Systems (henceforth NAPS) and several European customers to cover four years of production (Klitkou, 2010; Ruud & Larsen, 2005). The articulation of demand did not only secure 25 percent of the total investment from SND (which was estimated at NOK 70 million), but it also attracted financial supports from Nordlandsbanken and other private investors (Ruud & Larsen, 2005). Essentially, ScanWafer's first production facility had reached full by summer 2000, and the demand exceeded production capacity (Klitkou, 2010; Ruud & Larsen, 2005). The product was well received by customers, which includes NAPS, Eurosolare and Photowatt (Klitkou, 2010). Furthermore, the company signed two long-term sales contracts with Mitsubishi Electric Corporation (Melco) in Japan and Shell Solar in the Netherlands (Ruud & Larsen, 2005). At this point, production was expanded from 10 MW at the first facility to 50 MW at the second facility in Glomfjord, representing 25 percent of the world's market in 2000 (Klitkou, 2010), and making ScanWafer the world's largest producer of crystalline silicon (Klitkou, 2010; Ruud & Larsen, 2005).

At the initial stage, from 1994 to 2001, the institutions supplying capital and incumbent technologies influenced the performance of the capital market (Jacobsson & Johnson, 2000). Still at this point, the Norwegian government did not introduce any policy instruments targeted at the PV systems. One of the informants mentioned that there has been "a lot of financial support within the existing system", and "Norway has no tradition" of creating market opportunities for new business, new sectors or industries (Moen, 2012). However, Narula (2002) mentioned that the Norwegian government has intervened (through incentives) in the Norwegian industrial development, while targeting and shaping the development particular firms into "national champions". In the case of the Norwegian PV TIS, there were no specific incentives guiding the search, rather policies instruments targeted at renewable energy and environmental friendly technologies were allocated to support the R&D activities. Similarly, most of the informants mentioned that existing policy instruments promoting industrial development, research and innovation funded by the RCN, IN and Norwegian Industrial and Regional Development Fund played important role from 1994 to 2007.

As mentioned earlier, the Norwegian Parliament had prioritised funding of R&D on material technology in 1980s. Policy incentives such as EXPOMAT, (innovation programmes for export oriented material production and processing), established between 1991-1995 to improve silicon processing in material and NYTEK, the innovation programme for effective and renewable energy technologies, organised by RCN from 1995 to 2000 were thus allocated to support innovation activities in solar cells. (Klitkou & Godø , 2010; Fahlvik, 2012) Other programmes targeted to improve material technology such as PROSMAT (Innovation programme for processing and material technology), established from 1996 to 2001 supported the development of PV activities (ibid). In addition, Norway has over the years promoted the development of PV industry through the provision of cheap hydroelectric energy and other subsidies (Narula , 2002; Ruud & Larsen, 2005; Klitkou & Godø , 2010; Mühlbradt , 2012). Since the government's research policy has always promoted research activities in the silicon and material processing industry, it was natural for the Norwegian TIS to emerged and exist within these frameworks. Research, climate and energy policies[36] in Norway are critical for understanding this pattern. These policies are all interconnected, and their combined message was to reduce GHG emissions through increased R&D and efficient management of the Norwegian energy resources. From 1990 and up until 2005, these policies have mainly been induced to target basic research and research based on innovation in the field of energy. The overall aim was (and still is) to strengthen industry development through capacity and competence building in the areas of environmental friendly, Nano and new material technologies. These areas were highly significant for the development of environment and sustainable technologies, and hence PV. Such policy incentives were the innovation programmes such as VAREMAT (Innovation programme for industrial manufacturing and materials conversion), established from 2002 to 2005 and the research programme for Nanotechnology and new materials, NANOMAT established in 2004 supported the development of new generations of solar cells based on nanotechnology (Kaus, 2012; Juel , 2012; Klitkou & Godø , 2010). The research programme for User-driven Innovation (BIA), established in 2006 to support research-based innovation in the Norwegian business sector was also allocated to PV activities (Kaus, 2012; Kaus, 2012; Fahlvik, 2012; Foss, 2012). Other policy instruments of relevance are the Norwegian tax credit scheme SkatteFUNN, which was implemented in 2002 (Mühlbradt , 2012; Fahlvik, 2012). Under this scheme, companies engaged in R&D activities could apply for a tax deduction.

Although, no specific legislations or incentives guided the direction of the search, from the second half of 2008, the government on the basis of the Climate Agreement and in line with the research policy "A Climate for Research" increased R&D funding on renewable energy sources. These institutional processes had major influence on the renewable sector, and the PV system. For instance, since the agreement, the Government has implemented a number of measures to reduce GHG emissions, and some of these measures have had major impacts on the renewable sector, and consequently on the

[36] St. meld. nr. 29 (1997-98) Norges oppfølging av Kyoto-protokollen, St.meld.nr. 29 (1998-99) Om energipolitkken, St.meld. nr. 39 (1998–99) Forskning ved et tidsskille and St. meld. nr. 20 (2004-2005) The will to Research, St. meld. nr. 34 (2006-2007) Norwegian Climate Policy, and St. meld. nr 30 (2008-2009) A Climate for Research.

Norwegian PV TIS. First, the Climate Agreement and policy led to increase in governmental funding and the Norwegian PV TIS was a beneficiary. For Following the climate agreement, the Government has strengthened R&D funding in the development of environmental technologies in renewable energy, energy efficiency and carbon capture and storage with over 600 million (The Ministry of Trade & Industry and The Ministry of Environment, 2011). Consequently, the budget of climate related R&D activities, RENERGI doubled from 2008 to 2010 (The Research Council of Norway - RENERGI, 2011). When it comes to energy consumption and new technology, the Basic Fund (managed by Enova) established in 2007 with its capital of 10 billion, was increased to 25 billion after the agreement[37] (St. meld. nr 21, 2011-2012). Although Enova does not prioritise PV projects, and there is no specific funding programs targeted at PV consumption, PV projects can be funded as long as they are within the framework of energy efficiency[38] (Grønli , 2012; Heimdal, 2012). This is consistent with Jacobsson & Johnson (2000), who mentioned that legislative change might be required in improving the supply of capital.

As we have seen, although Norway lacks incentives specifically targeted at PV technologies, existing economic instruments were allocated to support R&D activities. Government's ambitious plan towards climate change and the reduction of GHG emissions also contributed to several initiatives in the renewables sector, and guided the direction of t search. Subsequently, the establishment of ScanWafer, REC and NorSun attracted new firms (see section 5.3.3) into the system, which in turn affected the selection process. However, after several years of development, several changes in the business environment, led to negative feedback in the system. As pointed out by one interviewee:

"I think the Norwegian government has supported the PV system, and intended to provide support. That is not however the problem. The challenge has been developing international market, which has made the market difficult. If you look back at the discussions about the REC, then you will find good statements on why the state does not go in and buy REC, and why the state do not put more money into the PV industry. It does not help to own the company, when the market is disappearing." (Helle Moen, Empirical Interview 29.11.12)

During the period between 2010 and 2012, the global market for solar cells experienced dramatic social economic changes in production capacity and falling PV prices. One contributing factor is that Chinese manufacturers have entered the global market, driving down the cost of PV and increasing competition. This led to overproduction, decline in equity prices and reduced profitability for upstream

[37] This means that Enova's budget has since increased. In 2012, revenues to the Energy Fund were estimated at about 1.9 billion, an increase of about 1.1 billion since 2007 (St. meld. nr 21, 2011-2012).

[38] One of the informants, Sverre I. Heimdal mentioned that Enova plays the role of new public management company with the mandate to stimulate market mechanisms that could contribute to the achievement of the national energy policy goals. He also mentioned that the company's main purpose is to manage energy fund in a way that would contribute to energy efficiency and renewable resources, and to disseminate knowledge and information.

actors and closures of factories in Norway. In addition the global financial crisis led to reduced government incentives in key market places such as Spain, Greece, Italy and Portugal. Since Norwegian players have mainly focused on customers in these markets, conditions from these markets have also led to fewer activities in the Norwegian TIS, resulting in downsizing and close of production facilities. Consequently, actors are now in the process of assessing existing technologies while exploring new areas. As pointed by one of the informants:

"I think we are in a critical phase, as PV is evolving, the technology is competitive and the prices are good. We must in one way or another way, manage to develop new ideas during this period so that both new and existing firms can be competitive when the time comes. If we keep manufacturing in Norway, it is clear that we can sell ideas when this period is over." (Gabriella Trannel, Empirical Interview 16.11.12)

Similar to Trannel's statement, many industry and research actors seem to focus on developing competence for niche product. This shows that Norwegian actors cannot compete on the basis of prices, but rather on technology and niche products. Evidently, most actors are interesting in producing niche products, which are cost efficient with high quality. It is however, essential that actors are guided toward a specific direction in order to create positive feedback in the system. Despite low level of industrial activities, NRC continues to fund research activities for PV technology shows a great willingness of supporting knowledge activities. Although, Norway still lacks incentives for the use of PV technology, there are several instruments currently available, which can guide actors during moments of uncertainties, and promote the diffusion of PV. For instance, policy instruments such as Technical Regulations for the Planning and Building Act, and the EU Building Energy Directive can stimulate the diffusion of PV in the construction market. Energy21[39] can also play an important role in setting industry's goals and agenda as well as creating incentive (see section 5.3.5). Another important framework that could guide the search is the government's ambitions in strengthening research activities in the development of environmental technology by 53 million (St. meld. nr. 30, 2008-2009). Subsequently, The Ministry of Trade & Industry and The Ministry of Environment developed a strategy for "The Economic Development and Green Growth" in 2011. In the strategy, the Norwegian industry is envisioned as a key provider of environmental and climate-friendly technologies (The Ministry of Trade & Industry and The Ministry of Environment, 2011). There is not yet evidence of its impact on the PV technology; however, the development of the solar industry in Norway is a good example of how Norway can play a significant role internationally as a technology developer and supplier, although solar energy is less used nationally.

[39] Solar United, which was established in 2009 with an annual budget of 20 million NOK (IEA PVPS, 2011) and RENERGI program are allocated to support the strategy

❖ **Strengths and Weaknesses in the Function "Influence on the Direction of Search"**

The main weakness of this function occurred between 1970s and mid-1990s. As we have seen, firms were reluctant in entering the system due to lack of governmental initiative. In addition, unfavourable landscape conditions guided the search away from PV technology, as Elkem was the only actors involved in PV activities. During this period, government incentives should be initiated in order to guide actors during economic crisis (and fell in energy prices). From mid-1990s, the establishment of the Norwegian PV TIS was a response to the strong political mobilisation in Europe for solar energy to meet the challenge of climate change and energy security. During this period, changes in landscape in Norway and other countries combined with actors' belief in growth potential as well as demand from major customers guided the search toward the production of wafer. Contrast to the German TIS, Norwegian government did not play major role in guiding the search. In the case of the Norwegian PV TIS, we witnessed institutional frameworks that emphasised more on promoting the production of scientific knowledge and less on the diffusion. Nevertheless, existing policy frameworks as well as the Norway's strategy toward R&D activities were allocated to support the system.

5.3.3 ENTREPRENEURIAL EXPERIMENTATION

The concept of innovation, as the driving force of economic growth is based on Schumpeter's work. Schumpeter rejected the neo-classical idea that viewed economy as machine or mechanic behaviour. Instead, he stressed on the role of the entrepreneur in the process of innovation and creative destruction[40] (Schumpeter, 1943, pp. 81-86). The entrepreneur is both the force of innovation and the driver of creative destruction. Schumpeter argued that the entrepreneur is a hero of the economy, because he takes risks during moments of uncertainties. This heroic act is the force that transforms knowledge into business opportunities. As such, the purpose of entrepreneurial experimentations is to reduce uncertainties. As illustrated in the case of wind tribune in Germany, the diversity of experimentations created variety and brought different type of knowledge and competence into the system (Bergek & Jacobsson , 2003). We see similar dynamics during the period between 1970s and early 1980s in the case Dutch of wind tribunes (ibid). In this case, firms entered the system, and experimented with various designs due unfavourable business conditions in their existing markets. As a result, variety was created through new knowledge, and subsequently, 15-20 companies were developing and producing different types of wind tribunes (Bergek & Jacobsson , 2003). These cases show that the entrepreneur is the facilitator of innovation.

[40] The notion of creative destruction is referred to the way market economies can destroy the old economy so that a new one can emerge. (Schumpeter, 1943, pp. 81-86).

According to Bergek and colleagues, technological experimentations are essential at all phases of the TIS (Bergek, et al., 2008a). Simply put by Carlsson & Stankiewicz (1991), "The role of the entrepreneur is to provide the stark or the visions to turns network into development block. He must be able to see beyond that which currently exists to what is possible in the future. He has to perceive the (future) need, identify the necessary ingredients, secure the resources that may be missing initially, and communicate his visions to the relevant agents – capitalists, suppliers of raw materials, people with the required skills, etc." In the Norwegian PV TIS, "the most important actor" during the mid-1990s and 2001 was Alf Bjørseth, "who saw the possibilities that lay in solar energy" (Ruud & Larsen, 2005). In the words of one interviewee, "It is often that the system [you] need a person to get things started" (Grimsrud, 2012) and Alf Bjørseth was certainly that person.

During the period between 1990 and 1994, Bjørseth was a Technological Director at Elkem (Tronstad, 2012). During the period between 1980s and early 1990s, Elkem "had ownership in the British company Crystalox", one of the leading producers of crystallisation furnaces for the production of silicon ingots (Tronstad, 2012) with the intention of acquiring the relevant knowledge in the production of silicon for solar cells. Bjørseth was a Chairman of the board at Crystallox, and developed interests for PV technology (ibid). As a Technical Director at Elkem, Bjørseth was responsible of developing plans for the production of wafer for solar cells (Ruud & Larsen, 2005; Klitkou, 2010; Tronstad, 2012). In 1993, Bjørseth presented his plans for Elkem's management. However, the company showed little interests as; it was at the time in the process of financial problems due to the fall in price for ferrosilicon products in the aftermath of the fall of the Berlin wall (Ruud & Larsen, 2005; Tronstad, 2012). At the same time, Reidar Langmo, leader of Meløy Næringsutvikling approached Bjørseth with the proposition of establishing a wafer production factory in Glomfjord (Klitkou, 2010; Ruud & Larsen, 2005). Bjørseth left Elkem, and his company Scatec AS founded ScanWafer in 1994 (ibid). Such, was the beginning of the Norwegian "solar adventure".

Initially, during the period between 1994 and 2001, the level of experimentations and the dynamics of new entrants was limited, and mainly dominated by Bjørseth's companies. In 1994, Bjørseth established Scatec AS together with Langmo. Through Scatec AS, Bjørseth started industrial adventure ScanWafer, Scancell, ScanModule, SiNor / SiTech and SolEnergy, the companies that later merged to Renewable Energy Corporation (REC) (Ruud & Larsen, 2005; REC Group, 2012; Klitkou, 2010):

- ✓ <u>Silicon and wafer:</u> SiNor: After the establishment of ScanWafer, Bjørseth founded SiNor in 1997 with the goal of becoming a leading provider of monocrystalline silicon for the international semiconductor industry (Teknisk Ukeblad, 2001). The company became a part of SiTech, which later became a subsidiary of REC under the name of REC Wafer Mono Glomfjord.

- ✓ PV installations: In 1998, Erik Sauar, Jan-Olaf Willums and Alf Bjørseth established SolEnergy with the goal of building regional manufacturing plants in various developing countries (REC Group, 2012). The idea was to build a complete facility that could compete in the off-grid market (Teknisk Ukeblad, 2001). The company planned to install 50 000 Solar Home Systems in South Africa, and built a small module manufacturing plant in Namibia (REC Group, 2012). Later, Japan and Germany launched major support programs for grid-connected solar energy, and the Namibian experiences in module manufacturing were taken further in ScanModule (ibid).

- ✓ Modules and cells: ScanModule AS established a plant in Värmland next to Arvika to serve the Scandinavian and North German market (Teknisk Ukeblad, 2001). Another company, ScanCell AS was established in 2002 in Narvik for the production of solar cells (Gram, 2008a). The bases for the production were silicon wafers from ScanWafer (Teknisk Ukeblad, 2001).

As mentioned, there are several solar-related companies under the umbrella of the ScanWafer (which later became REC). In 1996, an investment company, Fornybar Energy was established (REC Group, 2012; Ruud & Larsen, 2005). Two of the investors in ScanWafer, Hafslund Venture and Lyse Energi, became shareholders in Fornybar Energi (Klitkou, 2010). In 1991, Scatec AS became the biggest shareholder in ScanWafer, and invited other shareholders in ScanWafer to establish a holding company, REC (Klitkou, 2010; Ruud & Larsen, 2005; Teknisk Ukeblad, 2001). The two companies (ScanWafer and Fornybar Energy) were hence merged in 2000 into Renewable Energy Corporation. The purpose was for REC to develop activities in all part of the value chain. In 2002, REC was the only company with activities in all parts of the value chain, i.e. from production of silicon raw material to wafers, solar cells and solar cell panels, in addition to installations (Ruud & Larsen, 2005; Foss, 2012). The establishment of these companies gave birth to a supplying industry:

- ✓ Suppliers of raw materials: One of the most important elements in the production of mainstream activities is access to raw materials. The key element in actor's strategies was to secure access to cheap raw material. This is why suppliers of raw materials, such as Washington Mills and Norwegian Crystallites are important players in the supplier of raw material. Christiansen & Buen (2002) pointed that the threat of limited access to silicon provided a "focusing device and a source for innovative activities".

- ✓ Software solutions: Companies such as Prediktor, Noner Innovation AS and Tordivel Solar who have specialised in automation processes and other processes required in manufacturing of ingots, wafers, solar cells and modules provided added-value in the innovation process.
- ✓ Engineering and Procurement: BIS Production, Tronderud Engineering and EnSol AS represent another vital part in the Engineering and procurement processes.
- ✓ Machines & Utilities: The role of machines and utilities is also essential in the industry. Companies such as ABB AS, Eltek Valere, Artech and Ventro Solar, with mainly downstream customers, are involved in the productions of inverters, mounting systems, trackers and batteries and other machines necessary in setting up a PV system.
- ✓ Financial and Consulting Companies: Last, but not the least, are the roles played by financial and consulting companies in allocating and providing substantial among of financial support and knowledge to the industry. Consulting companies such as Aga Energy Services provides solar energy customers with technical, legal and financial services. Both private and public banks and venture capital companies have allocated financial resources in the industry. For example, Investinor AS, a government funded Investment Company, who invests in Norwegian companies in the early growth and expansion stages, have invested in both Innotech Solar and Metallkraft (Moen, 2012; Tuv, 2013).

During the period between 2000 and 2006, the technological knowledge was mainly concentrated on upstream activities. New comers such as Elkem Solar, NorSun[41] and Fesil Sunergy[42] introduced new ways of producing wafers or ingots, and dominated the industry. These actors introduced different elements to the upstream technologies. For instance, NorSun emphasised on premium high capacity of mono-crystal silicon ingots from high purity grade, FESIL Sunergy production technology of solar grade silicon has high cell efficiencies and Elkem Solar's solar-grade silicon is produced efficiently with low carbon footprint (Bugge, 2012). These new players helped strengthen the knowledge based of the system (see "Development of Positive Externalities" and "Knowledge Development and Diffusion").

[41] Established in 2005, NorSun has taped into a new type of customers by producing premium high capacity of mono-crystal silicon ingots from high purity grade. The company has a production plant in operates in Årdal with a production capacity of 200 to 250 MWp per year (Bugge, 2012).

[42] Fesil has developed a technology, which has the commercial advantage of reducing substantial amount of CO2 footprint, including 65 to 80 % lower capex and 20% to 40 % lower opex (IEA PVPS, 2011).

Parallel to this trend (new entrants with upstream activities), new companies were entering the midstream and downstream parts of the value chain, hence expanding the collective knowledge of the system. For example in 2001, Getek entered the midstream part of the value chain (Nilsen, 2012). The company delivers off-grid electricity supplying systems; based on solar panels, wind generators and diesel generators or a combination of these energy sources to create a hybrid system (ibid). The company also installs building integrated systems, and sells and distributes solar cell and modules. While Getek focused on the home market, Scatec Solar (established in 2005), which is owned by Scatec Group and Itochu Corporation, is involved in the design and construction of solar power plants in the international market (Osmundsen , 2012). ITS is also involved in the development and construction of medium to large-scale photovoltaic projects. ITS's process of regenerating defects cells is also another important value added to the system. ITS acquires defects cells from other producers, isolates the impurities through a laser technological process, and re-processed the cells into new cells. The cells are then used to produce modules (Tuv, 2013; Moen, 2012).

There are currently, similar trends in the system, where new entrants (mainly spin-offs) are entering all parts of the system simultaneously. For example, while CruSiN and CleanSi (Bugge, 2012)are entering the upstream part of the value chain, Fusion As is experimenting with downstream activities (Tuv, 2013) and other companies such as Ensol, Vonano and Crayo Nano are experimenting with new (generation type of) technologies. CruSiN As is involved in the production of silicon nitride crucibles for the production of ingot (Bugge, 2012). The company is a spinoff company from NTNU and SINTED research environment (see footnote)[43]. CleanSi, another new entrant has developed a new and cheaper method to produce silicon for solar cells of high quality and low cost using a new process technology[44]. In addition, EnSol is collaborating with the University of Bergen (Norway) and the University of Leicester (UK) in order to develop thin film cells that can be applied on body panels on cars, windows, buildings and other surfaces (Ensol AS, 2012). EnSol's objective is to enter the market by 2016 with a cell that achieves 20 percent of efficiency (ibid). Other (new) actors include Vonano, whose activities involve third generation solar cell technology, based on high performance tandem thin film solar battery architecture solution (Vonano, 2012). Crayo Nano is another actor involved in nanowire technology for PV cells.

While new players are experimenting with new technology, existing actors are experiencing a period of consolidations, downsizing and move of production facilities to Asia due to conditions brought by

[43] The company was sold to the French company, Saint-Gobain in 2011.
[44] Oslo Innovation Centre owns the company.

the financial crisis, overproduction and competitions from low cost countries. One of the informants mentioned that labour costs are the major cost of solar activities (Tranell, 2012). This high cost of production combined with competition from China, as well as economic recession in Europe and the rest of the world, have led to an increased competition, in which several upstream actors have closed down production facilities (Grimsrud, 2012; Heimdal, 2012; Moen, 2012; Kaus, 2012). Companies such as REC and Metallkraft AS have moved productions to Singapore. The company has downsized more than thousands employees (Aakvik, 2012; Qvale, 2012; Koren, 2011) and closed down all its production facilities in Norway[45]. Elkem also lost NOK 556 million in 2011 (Qvale, 2012). Consequently, productions in Kristiansand are stopped in august 2011, and the company laid off 150 employees (Koren, 2011). NorSun also laid off 220 employees by the end of 2012 (Teknisk Ukeblad, 2012). The three companies have laid over 1300 employees during the last two years and ITS laid off some of its employees in 2012. These conditions have also affected the supplying companies such Ekro Resirk, Metallkraft AS and Sic Processing (see footnote)[46]. For example, SOLSIC, FESIL's solar project was sold to Evonik Solar Norge in 2011, which is a subsidiary of German Evonik Industries AG (Bugge, 2012).

❖ Strengths and Weaknesses in the Function "Entrepreneurial Experimentations"

The number of new entrants and level of experimentations is diversified considering the geographical size of the country. At the beginning, the level of new entrants was mainly limited to the companies under ScanWafer (REC). However, the establishment of REC encouraged industrial companies (FESIL and Elkem) to experiment and enter the market. The establishment phase served as mechanism that reduced the level of uncertainties among actors, because primes reduced technological, financial and market uncertainties. Subsequently, experimentations through networks led to the establishment of Elkem Solar, NorSun and Fesil Sunergy, which in turn strengthened upstream knowledge, and led high level of clustering in the system in terms of ownership. As the system developed, actors are faced with international competitions from low cost countries, which have led to reduced industrial activities in

[45] Although the industry is undergoing major economic downturn, it is still highly dominated by The Renewable Energy Corporation As (henceforth REC), representing 58 percent of the total value of the Norwegian the solar industry in 2010 (Norwegian Renewable Energy Partners, 2010).

[46] Ekro Resirk has a partnership with REC, and SiPro has located a plant in Glomfjord to recycle REC's kerf. However, both companies closed down manufacturing plants when REC closed down all its production plants in Norway. Sic Processing is another company who took fall from REC's downfall in Norway. The company two plants, adjacent to REC Wafers operations at Herøya and Glomfjord with 100 employees. The company's operational activities were mainly concentrated around REC with a long-term slurry supply contracts with durations until 2019. In 2012, the company closed its production site in Herøya. As a result, 100 employees were laid off. Metallkraft was also affected. The company sold its manufacturing sites in Yangzhou and Kristiansand and shifted his head quarter from Norway to Singapore, in 2010 in order to serve REC.

Norway. As response, we see the new entries experimenting with midstream and downstream activities. There is an emergence of spin-offs from the research environment and new companies, bringing about new ways of processing wafers and ingots as well as third generation knowledge.

5.3.4 MARKET FORMATION

In order to stimulate innovation, it is essential to facilitate the creation of niche markets, where new technologies have a possibility to grow (Hekkert , et al., 2007). However, for a novel technology, markets may be not exist, or be underdeveloped (Bergek, et al., 2008a). As such, established technologies tend to have competitive advantage over the new technologies, mainly because there are relatively few actors and networks, and less developed institutions in the emerging technology (Bergek , et al., 2007; Jacobsson & Johnson, 2000; Carlsson & Stankiewicz, 1991). For example in the case of wind tribunes in Netherlands, the industry was locked into a local market that did not develop very fast in the 1990s (Bergek & Jacobsson , 2003). While in the case of Sweden, the market developed in the 1990s, but failed to respond to the growing demand (ibid). This function involves activities that stimulate demand for the novel technology. As mentioned in section 4.5.3, governmental legislation or subsidies are essential for the stimulation of market formation. These actions may help stimulate competition for renewable technology, and makes the technology accessible for end users. However, the case of PV in Australia illustrated that governmental incentives for R&D programmes did not stimulate the formation of market (Dewald & Truffer, 2011).

While most of PV-producing countries of global significance such as Japan, US and Germany have benefited from domestic market development (Klitkou & Coenen , 2013). The Norwegian PV TIS has mainly benefited from the international market. In terms of value, the domestic market for photovoltaic in Norway comprises only about 0.1% of world markets (ibid). Market formation is thus one of the weakest functions within the Norwegian PV TIS. There are two contributing factors for this development. First, the dominance of Hydro technology has contributed to major barriers for the adoption of public schemes that could induce market development for PV in Norway (Klitkou & Coenen , 2013). Second, Norway does not have any incentive schemes supporting the installation of PV systems, and consequently the use of PV technology in Norway is limited compared to countries such as Sweden, Spain, Italy and Germany. As a result, Norwegian PV products are exported and sold in the international market. This means that conditions from other countries have stimulated the formation of market for Norwegian actors.

Normally, market formation entails three phases, starting from a nursing over a bridging to a mass market (Bergek, et al., 2008a; Jacobsson & Bergek , 2004). Each phase is characterised by specific barriers, challenges (Dewald & Truffer, 2011) and attributes. During the period between 1970s to late 1990s, the main market for PV was off-grid. In the 1980's, Norway was one of the largest markets in the world for PV due to its high density of cabins (Ruud & Larsen, 2005), cabin and telecommunication market were hence important sources for income for the Norwegian actors (Bugge, 2012). However, from mid 1990s, the high demand for wafer for the productions of solar cells created market opportunity for ScanWafer (Klitkou & Coenen , 2013). This is because several countries, especially Japan and Germany launched major governmental programs for grid-connected solar energy, which represented market opportunities for Norwegian actors (Tuv, 2013; Ruud & Larsen, 2005; Klitkou, 2010; Mühlbradt , 2012; Heimdal, 2012). Some of the first customers of ScanWafer included Neste Advanced Power Systems, Eurosolare and Photowatt. The first two manufacturing plants in Glomfjord created a learning space for a "nursing market".

Dewald & Truffer (2011) mentioned that Japan, the USA and Germany dominated in PV technology in terms of market the development[47]. In Germany, Renewable Energy Sources Act (EEG) was one of the main drivers for market formation for Norwegian upstream actors (Dewald & Truffer, 2011). However, before EEG, the "1000 Roof Programme" introduced in 1990 was the first program for installing building-integrated PV systems in grid-connected applications (Ruud & Larsen, 2005; Jacobsson & Bergek , 2004; Dewald & Truffer, 2011). The "1000 Roof Programme" and the "Electricity Feed-in Law" (EFL) were the only available programmes for market formation, but were not sufficient for stimulating market growth for solar cells (Jacobsson & Bergek , 2004). As such, when the "1000 Roof Programme" reached its goal in 1995 (Ruud & Larsen, 2005; Jacobsson & Bergek , 2004; Dewald & Truffer, 2011), "100,000 roofs program" was introduced in 1999 (Jacobsson & Bergek , 2004). In addition to the "Renewable Energy Sources Act" (EEG)[48], a contract of 20 years between German authorities and producers was introduced in 2000 with the aim of reducing risks among investors (Ruud & Larsen, 2005; Dewald & Truffer, 2011). The market shifted from centralized PV power systems to small-scale homeowner systems with the introduction of the EEG[49] (Dewald & Truffer, 2011). These developments had strong impact on the upstream part of the value chain (ibid), since

47 These countries had some of the most successful industries, R&D facilities as well as ambitious subsidy schemes to promote PV technology (Dewald & Truffer, 2011).
48 The act was introduced in 2000, and was amended in 2004 (Ruud & Larsen, 2005).
49 With the introduction of the EEG, the total market in Germany increased from 69 MW in 1999 to 5340 MW in 2008 (Dewald & Truffer, 2011), and accounted of approximately 20 per cent of the world market in 2000 (Ruud & Larsen, 2005)

Germany had a limited production of wafers during this period (Ruud & Larsen, 2005). Germany became one the most important importer of upstream products, and Norwegian actors seized the market opportunities.

In Japan, the Sunshine Project introduced in 1974 to promote renewable energy, including PV was revised and reorganised in 1993 (Yamaguchi, 2001). The programme was yet again reorganised in 2000, which led to the establishment of the New PV Technology Programme. This programme was called Advanced PV Generation (APVG) (Ruud & Larsen, 2005). The intentions behind the programme were to reduce Japan's dependency on petroleum, and find ways of meeting the country's obligations under the Kyoto Protocol (Ruud & Larsen, 2005; Yamaguchi, 2001). PV was expected to be one of the key technologies in achieving governmental targets in the New Sunshine Program (Yamaguchi, 2001). In addition to these programmes, the Renewable Power Portfolio Standard (RPS) was introduced in 2003 with the aim of establishing market (Ruud & Larsen, 2005). Under this programme, there was a requirement that renewable energy should account for a fixed percentage of the electricity supply (ibid). Again, these initiatives represented market opportunities for Norwegian upstream players. For instance, Mitsubishi Electric (Melco) and Sanyo (Japanese companies) were important customers of REC.

With the introduction of the Japanese Ministry of International Trade and Industry initiative to subsidise the installation of 70,000 PV roofs by 2005 (Jackson & Oliver, 2000), and the Renewable Energy Sources Act (EEG) in Germany, the Norwegian market shifted from "nursing market" to "bridging market". During this phase, actors including suppliers, financial, recycling as well as engineering companies entered the system with complementary competence that increased the collective knowledge of the system. In regards to downstream and midstream activities, Norwegian players have mainly served the international markets. Markets drivers are similar to those of upstream activities. Companies such as ITS and Scatec Solar serves markets in Ghana, Burkina Faso, France, Germany, Italy and India among others. Another great example is Scatec Power, a holding company of Scatec, owns solar parks in Germany (Ole Grimsrud, 2012). Although, the market opportunities for these groups are currently to be found in the international markets, the Technical Regulations for the Planning and Building Act might may strengthen the competitiveness of solar energy in the future, and create a market for Building Integrated Systems in Norway. This trend is already in process. For instance, Oseana, which is Norway's largest building integrated PV project with 60 kWp 470 sq metre system integrated (Bugge, 2012) will be a typical PV projects in the future.

❖ Strengths and Weaknesses in the Function "Market Formation"

Up until mid-1990s, PV was widely used for leisure purpose. During this period, there were no upstream actors in the system. However, from mid 1990s, governmental initiatives in countries such as Netherlands, Spain, Italy and later Japan and Germany served as drivers of market formation in Norway. Although, Norwegian actors were competent in capturing opportunities in these markets, a lack of political support limited technology diffusion and market formation in the home market. Ruud & Larsen (2005) pointed out the importance of subsidy programmes for renewable energy in national budgets. In addition, several economists have stressed on the importance of governmental legislations in creating demand and forming market for novel technologies (Carlsson & Stankiewicz, 1991; Bergek, 2002; Bergek , et al., 2007). For example, Feed-in-tariffs[50] (FITs) remain one of the widely used policy instruments in some 61 countries in 2010 (REN21, 2011).

Although FITs have proven to be an effective policy instruments in promoting renewable energy (ibid), there is however, a difficulty in scaling the level of the tariffs in relation to the overall energy target in the feed-in system. For instance, setting high tariffs may lead to over investments, and price driving demand for new facilities, and setting low tariffs may not trigger investments at all. For countries such as Germany, Italy, Denmark and Spain FITs have been implemented to attract players in the market and improve the competition of renewable energy sources. However, in liberalised economies such as United Kingdom, Sweden and Norway, market failure initiatives such a Green Certificates may be most appropriate. Implementing the joint Swedish-Norwegian Electricity Certificates scheme in 2012 is Norway's long- term policy of fostering electricity production and consumption from renewable energy sources.

5.3.5 LEGITIMATION

As mentioned in the section 4.5.3, this function deals with "social acceptance and compliance with relevant technology" (Bergek, et al., 2008a; Bergek , et al., 2008b). It is essential for new technology to attain legitimacy, because it helps create demand and obtain political strengths (Bergek , et al., 2008b). Improving the legitimacy of the TIS, can mobilise both financial and human resource (F6), create motivation for new regulations and R&D incentives (F2), form new markets (F4) and increase entrepreneurial activities (F3). As the German and the Dutch wind turbines demonstrated, political consensus in 1980s attracted new entrants, and created variety in the system (Bergek & Jacobsson ,

[50] The purpose of Feed-in Tariff s (FITs) is support the market development of renewable energy technologies. Under the scheme, utilities and energy companies are legally obliged to purchase electricity from renewable energy producers at a favourable price per unit

2003). While the case of wind turbines in Sweden, lack of legitimacy limited actors' access to resources (ibid). Legitimacy is therefore a precondition for the formation of novel technologies (Bergek, et al., 2008a; Bergek , et al., 2008b).

This function is formed through conscious actions by various organisations and individuals in a socio-political process, which includes cognitive and regulative aspects (Bergek , et al., 2008b). As such, expectations and visions as well as regulative alignment, including issues such as market regulation or tax policies are central in creating legitimation. Several economists have stressed on the importance of strategy in creating legitimacy (Bergek , et al., 2008b; Bergek & Jacobsson , 2003; Bergek, 2002; Bergek, et al., 2008a). For example, one strategy for legitimation could be to conform to existing institutional frameworks (Bergek , et al., 2008b). In other cases, firms can either choose to influence existing framework through manipulation in order to achieve institutional alignment, or create new institutions (Bergek, et al., 2008a). The strategy used in the Norwegian PV TIS involved conformation of exiting institutions. For instance, one of the informants mentions that; "There is well functioning system such as Innovation Norway, The Research Council of Norway and Enova; all of them provide financial supports to companies all throughout their life cycles. There are good opportunities to support technological development in Norway including PV technology. More incentives have been allocated to renewable energy than traditional energy. For example, if one compares the sizes of the RENERGI program against PETROMAKS, there are more incentives awarded to energy technologies" (Moen, 2012).

One contributing factor for implementing this strategy is that the established technologies (Norsk Hydro's facilities) provided major opportunities for PV system to evolve. Moreover, there is a general perception that PV research competes in line with other research funding, and there is therefore no need of establishing specific regulations for PV related activities. In addition, the system evolved due to international demand and this influence the political agenda of most actors. There is therefore a lack of political expectations, visions and willingness in regards to PV's contribution in the country's energy and electricity consumptions. For instance, in 2003, the Energy and Environment Committee suggested a national strategy for the development of a global PV industry, with "Norwegian industry as a leading player" (Innst. S. nr. 48, 2003). In the bill, the committee asked the parliament to implement a national goal for the installation of PV on 100 000 roofs (in small commercial and residential) and on 100 000 m^2 facades for large buildings (ibid). The committee also proposed the establishment of a national demonstration facility for PV[51]. This bill was not adopted in the Norwegian Parliament due to several reasons.

First, the Oil & Energy Department stressed that Norwegian goals concerning energy consumption and production is to provide support to the most environmentally friendly and energy-saving technology in a cost effective manner (Innst. S. nr. 48, 2003). Enova was established with the mandate of achieving these goals (Grønli , 2012; Heimdal, 2012), and it is thus important that Enova have the greatest flexibility in providing support to relevant technologies (Innst. S. nr. 48, 2003). The establishment of a concrete target for solar facilities would be in conflict with Enova's role as a cost-and technology-neutral organisation (Innst. S. nr. 48, 2003; Heimdal, 2012). Instead of introducing new objectives related to certain technologies, The Oil & Energy Department suggested a general strategy, which could help strengthen environmental friendly and renewable technologies in Norway (Innst. S. nr. 48, 2003). These arguments are also consistent with the one of the interviewee, who mentioned that, Enova develops a program "that is quite general", which allows people to apply for a project within the program (Heimdal, 2012). Enova have not emphasized much on PV activities, but some programs open support for PV, because "people apply to see if they would get grant for their projects" (ibid).

The second, Norwegian solar industry was already well established in the world market due to increasing international demand (Innst. S. nr. 48, 2003). Establishment of a special target for PV in Norway, with the intention of building a home market for Norwegian solar industry was considered inappropriate (ibid). In the words of one interviewee, "I do not think the government envisages PV as will a contributing technology to the Norwegian energy production. I think the general perception is that PV has nothing to do in Norway, except for cabins. I think it is wrong" (Reenaas, 2012). Policy makers have not neutralised these negative expectations on PV. As such, lack of a national vision have until now contributed to a low legitimacy for PV power.

Although, the recent development of Energy21 could serve as national visions and expectations, and help create legitimacy for PV in Norway, it only induce knowledge development, as it cannot contribute to market formation (F4) or create legitimation (F5). Energy21 is the industry's research strategy with goal of increasing value creation through R&D and new technology, and for Norway to

[51] The following suggestions were also made in the same bill: "Parliament asks government to change guidelines for Norwegian aid assistance, so that PV could be prioritised, at least in line with other forms of energy, which Norway has, special expertise. Parliament asks the Government to take the initiative to establish a group of countries that practice "open bids" in aid contracts" (Innst. S. nr. 48, 2003).

become a net exporter of renewable energy and a technology provider in the future (Energi21, 2011). Most importantly, Energy21 focuses on enhancing the Norwegian knowledge within PV technology. Although, the effect of the strategy is yet to be measured, it set the course of a strategic direction, and the attention towards PV systems can help induce knowledge development through R&D activities.

❖ **Strengths and Weaknesses in the Function "Legitimation"**

Legitimation is the weakest function in the Norwegian PV TIS. Lacks of a national visions and political willingness have hampered the creation of legitimacy in Norway. One contributing factor is that Norwegian PV products are mainly exported. Consequently, the national Government is not interested in creation legitimation for the diffusion of PV in Norway. As such, actors focus mainly on creating political advocacy coalitions abroad. For instance, Alf Bjørseth, the founder and CEO of Scatec AS mentioned that they are represented in the board of Solar Research Centre in Singapore, which have heavily invested in PV R&D activities in Asia. He also mentioned that he is the Energy Advisor for the Singaporean Government and the company "uses these positions to establish an international network." (Bjørseth , 2012).

5.3.6 MOBILISATION OF RESOURCES

Resource allocation is crucial for the development, production and diffusion of new knowledge (Hekkert , et al., 2007). This function can be regarded as an important input to "Entrepreneurial Experimentation" and "Knowledge development and diffusion". It involves both financial and human resources that support innovation. In the case of PV in Germany, resources were mobilised from federal funding and private investments (Bergek , et al., 2007). Interviews with several actors have confirmed that both financial and human resources have been crucial to the development of technological and scientific knowledge in the Norwegian PV TIS. Despite, lack of legitimacy and weak market formation, resource mobilisation seems to be one of the strongest functions in the system. This section will start by looking at the financial mechanisms, followed by an examination of human resource and an assessment of complimentary assets.

5.3.6.1 MOBILISATION OF FINANCIAL RESOURCES

Lack of financial resources could hamper the development of emerging technology (Klitkou & Coenen , 2013). Although, resource mobilisation is essential to F1 and F3, it is also worth mentioning that the sources of these resources have great impact on the type of knowledge developed and diffused in the system. Analysing the dynamics of these sources has been helpful in understanding the purpose and performance of the financial resources. Financial and complimentary resources proved to be of great importance for *"knowledge development and diffusion"* from 1994 to 2007. For instance, at the initial stage, private investors, SND, Norsk Hydro and local government in Meløy municipality provided significant amount of financial resources that made the first ScanWafer's production facility possible. It is worth noticing that each investor had a motive. For Norsk Hydro and the local government, it was matter of saving jobs; securing infrastructures and economic growth in Meløy (see Complimentary Assets for more info). For private investors, it was a mater of seizing the opportunities to invest in growing market.

At the initial stage, 90 million NOK (Klitkou, 2010) were mobilised from different private investors, SND and Meløy Næringsutvikling in order to finance the construction of the first production facility of ScanWafer. During this process, banks loans from Nordlandsbanken enabled ScanWafer to gain access to offcuts[52] material in the Japanese electronics industry for the crystallisation process (Ruud & Larsen, 2005). According to Ruud & Larsen (2005), the access to raw material was vital in revealing and legitimising ScanWafer 's strategies for potential customers. The financial support of NOK 70 million from SND and Meløy Næringsutvikling attracted other private investors such as NSV Invest, Scatec, Fornybar Energi AS, Furuholmeninvest, Ficon Industri and Beam Holding (Klitkou, 2010; Ruud & Larsen, 2005). Private investments were as equally essential in the establishment of ScanWafer's second factory. This time, a total of NOK 240 million were invested and NOK 130 million were raised from private investors including Hafslund Energi and Lyse and Elkem (Teknisk Ukeblad, 2001). Once again, Norwegian Industrial and Regional Development Fund (SND) helped with grants and loans, while some part of the investment were financed with loan from DnB, and Scatec retained majority shareholding in ScanWafer (Teknisk Ukeblad, 2001; Ruud & Larsen, 2005; Klitkou, 2010). These investments were allocated to improve the technology and innovation activities, secure production activities in order to respond to demands from big market players such as Dutch Shell Solar BV from Netherlands, Mitsubishi from Japan and Motech Industries from Taiwan (Klitkou, 2010; Ruud & Larsen, 2005).

In addition, DnB and the Dutch company Good Energies contributed to NOK 90 million of investments in the establishment of ScanWafer factories in Herøya (Ruud & Larsen, 2005; Klitkou, 2010). During the process of establishing NorSun's production plant, a total investment of NOK 800 million were provided from private investors, public support and Norsk Hydro (Valmot, 2006; Gram, 2008b). In an interview with Teknisk Ukeblad, the Communication Director of NorSun, Sven Røst mentioned that the support from the public was scheduled to be about 10 percent of the establishment

[52] These are parts of the ingots are no more of value for the electronics industry.

costs (Valmot, 2006). He also mentioned; "the infrastructure facilities and elements such as access to cooling water are more important than the financial support" (ibid). In 2008, NorSun was valued NOK 1.4 billion in 2006 to NOK 4.6 billion due to solid investments of NOK 300 million from Good Energies (Strande , 2008), NOK 400 million from Norsk Hydro and other investors including the Japanese company, Itochu Corporation (Gram, 2008b; Valmot, 2006). Innovation Norway also contributed with NOK 30 million for financing job creation in in Årdal (ibid).

According to Hekkert and colleagues (2007), financial resources do not only include the aforementioned investments, they also included governmental investments such as R&D funds for the development of a specific technology as well as funds made available for testing and demonstrations. However, mapping government financial contributions have been of great challenge, since there are no programmes specifically targeted at PV activities. Financial resources from governmental fundings seemed to be more transparent during the momentum and the assessment phases of the *knowledge development and diffusion*. Moreover, financial resources from government were transparent from 2008 to 2012. For example, according to Klitkou (2010), government funding accounted for 12 million Euros for PV R&D in 2009. This figure seems relatively low given Norway's fortune in terms of income derived from energy production (ibid) and Norsk Hydro's total contributions of NOK 800 millions in PV activities in 2008[53] (Gram, 2008b). The governmental fundings allocated to support the system were originally targeted at R&D activities in Nano technologies, renewable and environmental technologies, entrepreneurial and industrial activities. These financial resources supported "entrepreneurial activities (F3) and the creation of new knowledge (F1). For example, the Norwegian government allocated a new program for commercialization of environmental technology with a budget of 500 million in the period 2011-2013 (The Ministry of Environment, 2010). Under this program, IN has provided a total of NOK 32, 2 million of funding to the solar industry (Innovation Norway, 2011). During the period between 2010 and 2011, NRC also allocated a total funding of approximately NOK 144 million for PV-related R&D projects (IEA PVPS, 2011).

In addition, most of the informants have confirmed applying or receiving funding from the RENERGI, BIA, NANOMAT[54] (changed to NOANO2020), PETROMAKS, FORNY and NYETK. The RENERGI[55]

[53] 50 million of these investments were allocated from venture fund, Convexa; which specialises in PV companies. About 250 million are invested in Ascent Solar, an American company that develops thin and flexible cells. Hydro's HyCore invested 160 million the pilot plants for production solar grade silicon and 400 million were invested in NorSun (Gram, 2008b).

[54] NANOMAT (Nano Material Technology), a research program within the field of Nano science, nanotechnology, microsystems and new materials has also allocated funding to solar activities. The program was merged with RENERGI and FORNY and in order to increase activities and improve the commercialization

program was established period between 2004 and 2013 to promote and increase research activities within the field of renewable energy, and has provided funding of NOK 150 million solar activities between 2005 and 2011 (The Research Council of Norway - RENERGI, 2011). In 2011, the program provided over NOK 35 million of funding to 14 solar projects (ibid). The RENERGI programs also funds graduate fellowships in industry and research institutions. The BIA program[56] has also provided over NOK 29 million of funding to solar related activities (The Research Council of Norway - BIA, 2011).

5.3.6.2 MOBILISATION OF HUMAN RESOURCES AND COMPETENCE

In regards to human capital and competence, Christiansen & Buen (2002) mentions that renewable energy companies have limited resources due to their organisational size, which in turn restrains them from establishing direct communication with large customers. These companies also have low bargaining power in terms of negotiation with large market players, and hence lack the power to influence institutional rules of the game (ibid). Their limited organisational capacities and flexibilities may obstruct them from participating in regulatory or legislative procedures. A possible strategy for dealing with this weakness is to establish alliances with educational and research institutes in order to obtain and exchange knowledge, which may help develop new competitive advantage (Christiansen & Buen, 2002). The mobilisation of human resources in the Norwegian PV TIS is illustrative, where mobilisation of human resources through collaborations between industry partners, research institutions and universities did not only mobilise financial capital into the system, but it also strengthened the collective knowledge of the system.

There are two types of strategic directions, which contributed to the mobilisation of human resources in the system. Since resources were limited, actors exploited external opportunities as part of recruitment strategies. The first strategies were based collaborations with local government and schools. The fact that most PV productions facilities were built on Norsk Hydro's old manufacturing plants meant that companies such as ScanWafer (later, REC) and NorSun had great access to skilled workers. In the words of one interviewee, REC had access to "experienced workers" with "certified competence" required for "that type of production setting" (Grimsrud, 2012). At this point, the industry

of new idea in the fields of nanotechnology, materials science and energy. FORNY allocates funds to new ideas and Technology Transfer Offices at universities.

[55] The program will be phased out in 2013, and will be replaced by ENERGIX, which will be put in place to support the implementation of the energy strategy, Energi21

[56] BIA is an innovation program, put in place to stimulate R&D projects corporate premises within topics not covered by other programs.

attracted people with various backgrounds from other professions such as auto mechanic, construction, retail and electrical engineering (Grimsrud, 2012; Klitkou, 2010). Klitkou (2010) mentioned that few of these employees had industry experience. Training and skills development were the essence in building and strengthening competence among employees. Collaborations with Meløy, Porsgrunn and Årdal municipalities were the core element in this strategic direction. It is also worth noting that these actors were motivated in providing jobs, and that helped facilitate funding for training and competence development. For example, Porsgrunn municipality invested NOK 10 million as a contribution to facilitate industrial site for new ventures.

Local Employment services also contributed in developing skills for people working in the PV industry[57]. Recruitment from local schools was also made possible through collaborations with High School and Technical Schools (Klitkou, 2010; Johansen , 2009). Through these partnerships, companies were committed to recruit students on placements. As such, most of the trainees were recruited from the schools, and in return, the schools offered education that provided the necessary theoretical knowledge in getting certificate. For instance, ScanWafer collaborated with Telemark Technical College[58]provided vocational education involving production, maintenance and line management (Johansen , 2009; Klitkou, 2010).

As the system developed, companies could attract workers that were more skilled than those from the initial stage. Upon the establishment of the second ScanWafer plant at Porsgrunn, the company attracted people from several manufacturing companies in Grenland, such as Union, Elkem and Norcem (Klitkou, 2010). In the case of NorSun in Årdal, the company recruited former employees from big companies such as Norsk Hydro, Doori, Lerum (producer of soft drinks and juices), Gilde and other industrial electrical and mechanical engineering companies were recruited (ibid). At this point, the focus of training and competence development shifted to more advanced industrial skills and knowledge such as manufacturing and material processes (Klitkou, 2010). [59] NorSun's collaboration with PRO Training office for process and engineering industry is an illustrative case. The training focused mainly on production principles, in which "lean manufacturing" was central (Klitkou, 2010).

[57] For example, in Glomfjord, ScanWafer teamed up with the local Employment Service for a qualification course for working in ScanWafer. In this agreement, ScanWafer was responsible of providing instructors while the Employment Service was responsible of organising the course as well as providing employment benefits, since the vast majority of the participants were unemployed (Klitkou, 2010 (Johansen , 2009)).
[58] Up until 2009, Telemark Technical College provided continuous training to REC's employees. However, in 2009 courses were reduced due to the company's poor economic performance.
[59] The training included courses such as product knowledge, materials science and process knowledge, quality, production control and materials management, safety, optimal use of machinery and equipment, maintenance, Collaboration and Management and Introduction to robotics (Klitkou, 2010).

Furthermore, strategic partnerships with universities and research institutes became more transparent. This leads to the second strategic directions that help mobilised highly educated personnel into the system.

As the industry entered the growth phase (refer to section 5.4), research institutes and universities played significant roles in strengthening the collective knowledge of the system. Christiansen & Buen (2002) pointed out that failing to identify common problems may prevents both the research and industrial communities from mobilising resources required for overcoming critical barriers. In the case of the Norwegian PV TIS, during momentum phase of F1, access to raw materials and the creation of new knowledge were critical success factors. Development was not only limited to access to raw materials, but technological skills and knowledge were also important supplement for the creation of new knowledge and development of core competence. A common goal between industrial and research actors were to mobilise relevant educational programs as well as skilled researchers into the system (Klitkou, 2010; Juel , 2012; Tranell, 2012). For example, NTNU is running a PhD-programme on end use of photovoltaic technology in partnership with Elkem Solar, and the UiA is running PhD-programme collaboration with Elkem Solar (Tranell, 2012; Tronstad, 2012). The company also collaborates with the research institute Teknova, Aarhus University, Photovoltaik- Institut Berlin and ISC Konstanz (Tronstad, 2012; Tranell, 2012; Juel , 2012). The programme involves Field- and accelerated laboratory testing of solar grade silicon modules. As part of these collaborations, research institutes and universities host PhD candidates for industrial actors.

Upon the entering of the research groups, the nature of competence development shifted to formal type of education. These groups are preoccupied with educating researchers, and offering competent human resources with knowledge in the field of energy and environment technology, metallurgical processes, material technology and etc. One of the interviewee pointed; "our main assets is that we have the country's brightest technology students, period. We have extreme good students. With the right attitude, these students would develop the necessary skills. This is in a way our advantage. That is where we can help" (Tranell, 2012). These research groups can provide individual with great deal of technological and other relevant knowledge. At SINTEF, more than 50 people are involved in research on feedstock, refining and crystallisation, sawing and material characterisation SINTEF. The research team in the division of Materials and Chemistry has activities focusing new sources and production methods for silicon to solar cell applications and fundamental research on materials for photovoltaic (Bugge, 2012). Furthermore, at MiNaLab, a research team of 55 people is involved in the development of new PV cell technology. The research group at UiA on PV technology also counts about 10 persons, including 3 professors, 1 associate professor, 1 postdoctoral fellow and 4 Ph.D. students. In other words, the industry has great access to qualified human resources (Bugge, 2012).

5.3.6.3 COMPLIMENTARY ASSETS

In addition to financial and human resources, complimentary assets have proven to be great input of innovative process, and were vital for the establishment and momentum phases of *"knowledge development and diffusion"*. This is because during the period between mid-1990s and 2005, most PV production facilities were built on Norsk Hydro's old productions plants. One interviewee pointed out that "there was money and infrastructure available" for the "establishment of production facilities" in Glomfjord, Herøya and Årdal.

From the period between 1993 and 2005, Norsk Hydro was in the process of closing down factories in the Northern, Southern and Western regions. The fertilizer production in Glomfjord started after the war in 1949 (Klitkou, 2010), and the municipality was developed around the Norwegian Hydro's ammonia plant. However, the Norwegian Hydro's ammonia production was discontinued, and several industrial employees were to be made redundant (ibid). In order to save jobs, the Norsk Hydro founded in 1992 Glomfjord industrial park, where the factory was located (Klitkou, 2010). In 1993, Norsk Hydro wanted to stimulate new industrial activities, since it was at that time in the process of closing down its own artificial fertiliser production plant, which it owned together with Meløy Næringsutvikling (Ruud & Larsen, 2005; Klitkou, 2010). As a result, Bjørseth took over Norwegian Hydro's ammonia plant for the production of silicon wafers (Bjørseth , 2012; Grimsrud, 2012; Ruud & Larsen, 2005), and his company Scatec founded ScanWafer (Klitkou, 2010; Grimsrud, 2012).

Collaborations with Norsk Hydro continued in the establishment of the ScanWafer's third and fourth production facilities in Herøya (in the Southern region) and NorSun's production facility in Årdal (in the Western region) (Christiansen & Buen, 2002; Klitkou, 2010). In 2000, Norsk Hydro decided to close the magnesium production in Herøya (Klitkou, 2010). The company had industrial and research activities in Herøya since 1928 (ibid). These activities were mainly related to the production of fertilizers, magnesium and plastics. In the 1980 - and 1990s the Norsk Hydro in Porsgrunn went to several processes of downsizing because the manufacturing plants in Grenland were too small to be competitive, and there were no government incentives supporting knowledge development (Klitkou, 2010). The closure would have led to loss of jobs in Porsgrunn. In 2001, ScanWafer and Norsk Hydro entered an agreement involving taking over employees for the construction of a ScanWafer plant in Porsgrunn Business Centre for the production of silicon wafers for solar cells (Klitkou, 2010; Ruud &

Larsen, 2005). In the agreement, ScanWafer was assured access to a large industrial environment, supply of process and research expertise through exiting employees and infrastructure; and in return, Norsk Hydro could allocate existing jobs into the PV industry.

A similar process took place between mid-2000s and 2007, upon the establishment of NorSun's facility in Årdal (Ruud & Larsen, 2005; Klitkou, 2010). The initial plan was for REC to take over an old Norsk Hydro's Søderberg facility in Årdal (Ruud & Larsen, 2005; Steensen, 2007). In early 2000s, Norsk Hydro was planning to close down its Søderberg furnaces facility in 2007 due to lack of competitive power prices (Steensen, 2007). The facility had been in operation since 1962, and its closure meant downsizing 90 people in the village of Årdal (ibid). As a way of ensuring a sustainable economic stability in the area, Årdal municipality and Hydro Aluminium established Årdal Future in 2004 with the aim of developing large industrial project, thereby creating new jobs that would replace those that would have been lost upon the closure of Søderberg in 2007 (Steensen, 2007; Klitkou, 2010). SIVA decided that Årdal would be an industrial hub, which could attract new industries (Steensen, 2007), and the area was identified as an alternative location for ScanWafer, because of great financial support and an established industrial environment. However, due to lack of enough funding, the company made a strategic decision of not pursuing plans in Årdal, and instead expanded its existing facilities in Herøya. As a result, NorSun, a new comer created by Scatec-founder, Alf Bjørseth (Ruud & Larsen, 2005) seized the opportunity to establish an agreement with Norsk Hydro and SIVA. As a part of this agreement, SIVA built the plant, and leased it to NorSun (Ruud & Larsen, 2005; Steensen, 2007).

Other complimentary assets included access to research facilities. The strategic alliance between SINTEF and NTNU include joint use of laboratories and resources at the Hiliosi Clean Room Laboratory and Gemini centre (Bugge, 2012). Through this partnership, SINTEF staffs teach at NTNU and NTNU personnel work on SINTEF's projects[60]. In 2011, UiO and SINTEF established research collaboration through MiNaLab, or Centre for Materials Science and Nanotechnology (ibid). MiNaLab covers activities on semiconductor process technology, characterization and photovoltaic, with special emphasis on new materials for solar cells and for utilization of electricity (Bugge, 2012). This knowledge can contribute to the development of third generation solar cells (F1).

[60] The main activities of the centre involve solar cells and solar materials, in which the centre works with characterisation methods in multicrystalline solar cell material along with the development of third generation solar cells (Bugge, 2012).

❖ **Strengths and Weaknesses in Function "Mobilisation of Resources"**

As mentioned, mobilisation of resources is one of the strongest functions within the Norwegian PV TIS. Financial and human resources as well complimentary assets have been progressive during the different phases of the system. At each phase, resources were mobilised to serve specific goals and purposes. In terms of financing and funding, there is a willingness of allocating financial resources into the system. In addition, the relationship between industrial players and research institutes and universities has further strengthened the collective competence of the system.

5.3.7 DEVELOPMENT OF POSITIVE EXTERNALITIES

According to the neo-classical economics theory, the concept of "positive externalities" refers to the benefits of innovation (or knowledge) spillovers to other actors from the firm undertaking the investments (Bergek , et al., 2007). These external economies are often referred to as "free utilities", new knowledge, cost reduction, reduction of uncertainties, combinations of knowledge or in the case of PV, the supplying of raw materials such as silicon (Carlsson & Stankiewicz, 1991; Bergek , et al., 2008b; Bergek, et al., 2008a). Entry of new firms is vital for the development of the positive externalities, because new entrants reduce uncertainties, guide the search (F2) and stimulate market (F4) (Bergek, et al., 2008a). Wind turbine in Germany is a great illustrative case, where new entrants increased the political power of the system as well as aligning the institutional framework to the TIS (Bergek & Jacobsson , 2003). In addition, the emergence of specialised suppliers lowered the entry barrier of the system (ibid).

Four forms of positive externalities can be found in the Norwegian PV TIS. First, knowledge spillovers contributed to the dynamic of the function "*knowledge development and diffusions*". Bergek and colleagues (2008a) pointed out the importance of knowledge spillovers in shaping external economies, and expanding structural components, such as networks and institutions. In the Norwegian PV TIS, these spillovers occurred during different periods in the development of the system. During the period between 1970s and 1990s, Elkem's technological activities in aluminium industry had spilled over to silicon processing (Klitkou & Coenen , 2013; Tronstad, 2012) due to the company's interactions with customers and the acquisitions of relevant knowledge (refer to knowledge development and diffusion in section 5.3.1). Later in the 1980s, governmental programmes from Japan and Germany increased the global demand for silicon for PVs, and provided a market for Norwegian actors. From mid-1990s to 2001, the technological knowledge developed in the Elkem environment was essential in the establishment of the system. In addition to the technological backgrounds of actors (Entrepreneurial experimentations), access to the right competence and complimentary assets (Mobilisation of Resources) were essential elements in the establishment of ScanWafer, ScanCell, ScanModule, SiNor/SiTech and SolEnergy, companies, which later merged into REC. The PV industry also benefited from knowledge spillovers from different types of co-located processing industries, such as pulp and paper, but also from the automation and lean production concepts of the automobile industry (Klitkou, 2010; Klitkou & Coenen , 2013; Ruud & Larsen, 2005). In addition, the establishment of PV companies in Glomfjord, Herøya and later Oslo induced spillovers to several companies (FESIL Sunergy, NorSun and Elkem), who offered different types of productions processes and products. It is also worth mentioning that, downstream players have benefited from the offshore sector in areas such as project management.

The second form of positive externalities involves the emergence of intermediate services and goods. According to Bergek and colleagues (2008a), the emergence of these actors can contribute to cost reduction, and stimulated knowledge development and diffusion. The establishment of a PV industry led to the emergence of companies in related supplying industries. For example, ScanWafer's activities in Glomfjord attracted new entrants involved in recycling technologies, which had somewhat improved the understanding of the wafer production. These companies (Si Pro AS and Sic Processing) provided technologies involving recycling of waste silicon, which were essential in reducing the disposal of waste, hence reducing production costs. For example, during the process of sawing ingots into wafer, the silicon produces dust called kerf, in which the approximately 50% of the ingot is wasted. This means that the production of wafer is highly expensive. Actors such as Ekro and Si Pro AS have developed technology and knowledge that removes the impurities from the cutting process, hence turning the kerf loss into usable feedstock for solar applications. The wafer cutting process is another complex step in the production of solar panels. This process requires large amounts of cutting slurry. The slurry needs to be continuously replaced with fresh slurry and disposed in an environmentally way. Companies such as Metallkraft and Sic Processing AS recycle the slurry retaining its cutting abilities without adding any chemicals. With this technology, 80 per cent of the cutting fluid will be recovered (Ruud & Larsen, 2005). In addition, companies such as Molab As[61] and BIS Production Partner[62] involved in environmental analysis and maintenance services, established in the same area, and brought value to the PV industry. Innotech Solar's activities in the Northern region are

[61] Molab as is a subsidiary of SINTEF, and performs industrial analysis and environmental analysis. It serves metallurgy and mining, and has expertise in the analysis of silicon carbide used in cutting fluids for sawing wafers and silica dust.

[62] BIS Production Partner is a player in the European market for the supply of maintenance and project services.

also worth mentioning. Moreover, companies such as Ekro, Metallkraft, Si Pro As and Sic Processing AS established to subsidiaries in the same area (Herøya) in order to serve the PV industry. Moreover, Scatec Solar and Scatec Power were established in Oslo as spin-offs of Scatec AS. The same trends can also be found in the Southern region, at the establishment of Elkem Solar, which attracted new actors such as Teknova, Isosilicon, Eltek Valere, Vetro Solar and Metallkraft.

The Development of positive externalities is central to the formation of clusters and innovation systems (Bergek , et al., 2008b; Carlsson & Stankiewicz, 1991), because it reflects on the strength of the collective dimension of innovation process (Bergek , et al., 2008b), and increases the strengths of the other functions. For instance, new entrants may generate positive externalities that reduce cost of entry; networks may be expanded and universities and research institutes may expand their research and education in the relevant knowledge fields (Bergek , et al., 2008b). The third form of positive externalities is related to the entry of new firms. With the entering of new firms at the upstream level of the value chain, the focus on upstream products was strengthened, and a change in the institutional set-up occurred, in which the universities and the research environment were aligned to serve the system. This is also consistent with Hanson (2008) who mentions that "the momentum phase the industry has matured, and institutional changes become increasingly embedded in the NIS". Interviews with both research and industry actors have also confirmed that the involvement of research groups resulted in increased level of learning processes through networking (interactions) and searching, which has in turn improved the scientific and technological knowledge of the system. The entering of research groups led to two directions of knowledge development: (i) it increased the level of R&D activities (scientific knowledge) in the system, hence strengthening competence in upstream activities, (ii) and expanded networks and the dynamics of collaborations.

In regards to scientific knowledge, although "the research and universities environments did not start joint projects with the industry until late 90's" (Tronstad, 2012; Grimsrud, 2012; Bjørseth , 2012), they have over the years developed strong relationships with industry actors. This is well expressed by Gabriella, a research leader from NTNU:

"From my own professional perspective, I think NTNU and SINTEF have been significant, for the development of Elkem Solar photovoltaic processes. Similarly, SINTEF has also been the essential background for the entire process of FESIL SUNERGY. From my perspective, from upstream solar, we have played an enormous role. This process would not have been possible without our existence." (Gabriella Trannel, Empirical Interview, 16.11.12)

The statement above is well reflected in the dynamics of the scientific knowledge. Learning took place through R&D activities with both international and national research institutes and universities. For example, in order to meet future growth, ScanWafer and Elkem initiated a network-based project, called "From Sand to Solar Cells" with NTNU, involving both academics and industry representatives. The purpose was to investigate the production of so-called solar grade silicon, SOG-Si. In addition, Elkem collaborated with SINTEF and The University of Konstanz in Germany (Tronstad, 2012; Tranell, 2012; Kaus, 2012) as well as research centres in Japan, Australia, USA, Denmark and Sweden in order to verify the quality of the processes developed through Elkem Solar (Tronstad, 2012). These players have covered "different type of knowledge" (ibid) during the development of the Elkem Solar's activities, and allowed the company to improve its material to industry standard[63]. Similarly, SINTEF and FESIL Sunergy collaborated with the Swedish company ScanArc and ECN (Tranell, 2012), the largest research institute in Netherlands in developing a process for the production of solar grade silicon.

In regards to network dynamics, the entering of new entrants also increased collaborations and strengthened networks. One of the interviewee, a research leaders at NTNU, Grabriella Trannel (2012) stressed on the importance of "person-to-person interaction", a type of informal learning, which is essential in creating new knowledge and exchanging information. For example, the fact that NTNU and SINTEF are geographically located in the same area, create an environment for learning and knowledge spillovers. Another example is the geographical proximity between Teknova and UiA, which allows both players to interact and collaborate. These types of forums organise seminars and conferences in which information is disseminated. Teknova is also working on a major project related to degradation of the solar cell material under environmental stress in collaboration with Elkem Solar (Imenes , 2012; Bugge, 2012). In addition to the national networks, international networks are significant for the learning and diffusion of knowledge. In an interview with the Vice President Research & Development in Scatec, Ole Grimsrud simply summarised the importance of international networks:

"Alf likes to say: "99 percentage of innovation happens outside of Norway". We have to be international. The PV system is an international industry, so we look outside Norway. We have good internal network, so we can access the technologies that are developed in the silicon industry." (Ole Grimsrud, Empirical Interview 29.11.12)

[63] In Sweden, Elkem Solar collaborated on the verification of process-related activities in metallurgy. With regards, to material quality of the silicon solar cells and alternative processes, the company cooperated with the research environment in Denmark and the USA. In addition, the products were promoted in the Japanese research community in order to attract customers. In regards to Norwegian institutions, Elkem Solar worked with IFE on modulation and verification of products in the solar cell venture in Kristiansand and on research on modules with Teknova and UiA.

The statement above seems to be the general understanding among several actors who have established strong networking relationships with universities and research institutions in Japan, China, USA, Sweden, Denmark, Germany, Australia, China and Europe. Other international networks include sharing and exchange of information through the participations in IEA PV programmes. At the European level, Mari Juel, a researcher from SINTEF mentioned that "the participation in European networks is vital", because "it allows us to influence and share information" with other players at European level (Juel, 2012). Juel's statement is well reflected in EU programs and SET Plan[64], where Norwegian actors are well involved. For example, in their work on new sources for feedstock to the solar cell industry, SINTEF is involved in a number of EU projects and programmes in collaborations with European industry, universities and research institutes.

The fourth form of positive externalities involved the emergence of pooled labour. During the period between 1994 and 2007, former employees from Norsk Hydro, Elkem were recruited to ScanWafer and REC. For instance, Dr David Hukin founder of Crystalox, which was formerly owned by Elkem, and other former employees of Elkem were recruited to work in ScanWafer. Subsequently, new entrants had access to the knowledge of early entrants by recruiting former employees from REC and other research institutions. For instance, ITS, NorSun and Scatec all recruited from REC, SINTEF and IFE.

❖ Strengths and Weaknesses in the Function "Development of Positive Externalities"

As mentioned earlier, this function strengthens the dynamics of all the other functions. As illustrated, the establishment of the Norwegian PV TIS has created four importance externalities that have created dynamics in the other functions. First, knowledge spillovers from Elkem contributed to knowledge development and diffusion, which led to the establishment of the PV industry. Spillovers from other industries have further increased the knowledge base of the system. Second, the emergence of a supplying and service industry contributed to cost reduction, created interest among customers and strengthened the functions "knowledge development", "Influence on the direction of search" and "Entrepreneurial Experimentation". Third, new entrants brought new type of knowledge to the systems, which helped strengthened "knowledge development and diffusion". In addition, the entry of the new

[64] In regards to the SET plan, SINTEF participates in EERA's joint programme on Photovoltaic Solar Energy. EERA is an important part of the EU SET Plan for implementation, and actively seeks to contribute to EPIAs SET Plan 2020 through major R&D activities, which will contribute to cost reductions in PV technology. SINTEF is also involved in the establishment of EMIRI, and the initiative will operationalize the SET-Plan Roadmap for Energy Materials covering 11 areas of technology in the form of an implementation plan (including photovoltaic).

firms introduced variety to the system, and universities and research institutions were aligned to serve the industry. They also increased the dynamics of the networks, which subsequently strengthened the development and diffusion process and "Entrepreneurial Experimentations". Finally, the emergence of pooled labour helped mobilised human resources into the system, which reinforced the function "Knowledge development and Diffusion" and "Entrepreneurial Experimentations".

5.4 FUNCTIONALITY AND OVERALL GOALS OF THE NORWEGIAN PV IS

Having mapped the structural components as well as the seven key functions in the Norwegian PV TIS, this section will assess the "goodness" of the functions in order to understand how well the system is performing. In doing so, the performance of the functions will be analysed in respect to the key requirements of each phase. As mentioned in section 4.5.4, Bergek and colleagues (2008) suggested assessing the development phase of the TIS as well as comparing the focal TIS to other systems when assessing the performance of the TIS. Since every function has been compared to other TIS in Germany, Sweden and the Netherlands, this section will mainly focus on assessing the functional dynamics at each phase of the system and the goals.

In section 4.5.4, a distinction was made between a formative and growth phase in the development of new TIS. However, the assessment of the seven functions indicates that the Norwegian PV TIS has passed through four phases: the first research activities were held between the period of 1970s and 1980s in *the pre-production phase*, and governed by "the influence of search". The first decade of the formative phase (1980s -1990s) was characterised by Elkem's explorative activities with continuous searching and developing knowledge through interactions and acquisition of competence. In the next period of *the formative phase* (1990s – 2003), the knowledge developed in the Elkem environment spilled over to new actors, and was led by external and institutional changes such as international demand. The establishment of the first company led to new firms entering the upstream level of the system during the last stage of the formative phase and early period of the growth phase (2003 – 2008). With the entry of the new firms, the knowledge base of the system was increased in *the growth phase*. Subsequently, new knowledge was developed, and new firms entered various part of the value chain. However, unfavourable landscape conditions occurring in late 2008 led to *the decline phase*.

5.4.1 THE PRE-PRODUCTION PHASE

During the first phase, in 1970s, the development of scientific knowledge was triggered due to the oil crisis of 1973. This crisis resulted in institutional change guided by the Ministry of Oil and Energy (F2) through the establishment of a working group, which coordinate PV R&D activities among actors[65]. Subsequently, R&D support for the investigation of separation techniques and production of metallurgical-grade silicon was initiated (F1). The goal was to increase Norway's knowledge in the field of renewable technology. However, in 1980s, actors' interests decreased, because of unfavourable energy prices. Consequently, the level of R&D support for PV activities diminished (F1). At the same time, a new guidance of the search, directed toward R&D in material technology was initiated by parliament. At this point, government failed to guide the search (F2), and the consequences are seen in the "Entrepreneurial Experimentations" (F3).

Despite the fact that several actors had extensive knowledge in the production of silicon, in addition to favourable energy access, failure to influence direction of the search led to limited research (F1) and experimentations (F3) in PV technology, and created negative feedback loop in knowledge development (F1). Elkem was at the time the only company experimenting with PV activities. Lack of mechanisms for supporting entrepreneurial experimentations and unfavourable attitudes towards PV technology combined with government favourable support of other RNE such as wave, hydro and bio (Christiansen & Buen, 2002; Klitkou & Godø , 2010) did not create externalities at the end of the oil and energy crisis. In addition, low legitimacy (F5) meant that the goal of developing knowledge in PV technology was not completely fulfilled. Although, Norway was one of the largest markets of off-grid in the world, no instrument were initiated to stimulate market formation or to encourage entrepreneurial experiments – apart from R&D support for the development of scientific and technological knowledge.

5.4.2 THE FORMATIVE PHASE

According to Jacobsson and Johnson (2000), the formative phase involves three structural processes including entry of firms (and other organisations), the formation of networks and institutional alignment (Jacobsson & Johnson, 2000). These structural processes begins in the formative phase (or pre-development), (Jacobsson & Bergek , 2004), where the level of adoption of a new technology is low. The technological and market uncertainty is high, and entrepreneurial experimentations are essential in creating variety in the system (McKelvey , 1997; Bergek, et al., 2008a; Bergek & Jacobsson , 2003). In the Norwegian PV TIS, the formative phase last for several decades, and Elkem (the only actor in the system) guided the search through technological and production experimentations (F3) during the first period of the formative phase (1980s – 1990s). The goal was to develop new knowledge through the explorative activities. Interactions with existing market and the acquisitions of new skills (Crystalox and Union Crucibles) supported the development of new knowledge (F1).

[65] Institutions, universities and companies

Nevertheless, negative feedback loop triggered from institutional framework and the economic crisis of 1990s discontinued Elkem's plans involving wafer production (F1). Normally, public support can help stimulate the creation of knowledge by encouraging entrepreneurial experimentations. As seen in the German wind turbines, R&D policy was used as a mechanism of encouraging technical experiments. However, there were no mechanisms stimulating entrepreneurial experimentations in the Norwegian PV TIS. From early 1990s, development was triggered by efforts coming from one entrepreneur to proceed with Elkem's original plans, and local government attempting to save jobs (F2). This brought in the mid-1990s to the establishment of the first production facilities in Glomfjord (F3). From 1994 to 2000, the goal was to develop knowledge based on existing competence. This led to changes in institutional set-up and the transfer of knowledge between incumbent and novel technologies. At this point, industrial knowledge from existing workforce (F2) was relevant during the first production process (F1 and F2). Moreover, local government's ambitions in saving jobs guided the search by providing infrastructure and allocating regional policy instruments to support the production activities in Glomfjord (F2). Despite unfavourable economic conditions and lack of market incentives *(F4),* articulation of demand from major players (F2) encouraged private investors in mobilising both financial and human resources (F6) into the system.

From 2000 to 2003, the goal was to secure access to raw materials and reduce production costs. During this period, experimentations did not involve R&D capital investments; still system goals and competitive advantages were achieved. There are three main reasons that have triggered these positive feedbacks, and they can be explained through the functions knowledge development and diffusion, entrepreneurial experimentations, resource mobilisation and the creation of positive externalities. First, upon the establishment of factories in Glomfjord, several firms experimented with supplying services and technologies (F3), and contributed to cost reduction, which improved production and induced knowledge development (F1). The second reason can be found in the learning and organisational processes of the main actors. Interactions between users and suppliers served as a precondition of knowledge development and diffusion (F1). The acquisition of sawing and furnaces technologies combined with collaborations with Prediktor and Tronrud Engineering improved production conditions. In addition, collaborations with Elkem, SunPower, Elkem Solar and the acquisition of Solar Grade Silicon helped secure access to raw materials. Third, knowledge spillovers (F2) from the processing and the automobile industries further improved production knowledge (F1), which in turn increased the articulation of demand from major players in Japan and Germany (*F2*). Fourth, although lack of initiative to support the diffusion of PV technologies (F5) created market opportunities for

Norwegian actors (lack of market formation), actors' expectations (F2) and local government's ambitions to once again save jobs combined with favourable market conditions in Germany, Japan and many other countries created an international market for Norwegian actors. At this stage, the focus shifted from developing new knowledge to strengthening exiting upstream knowledge. Consequently, the system entered in to the growth phase, and universities and the research environment were aligned to serve the system.

5.4.3 THE GROWTH PHASE

According to several scholars, the formation of markets can generate a space, which could provide incentives for the entry of firms into various parts of the value chain (Bergek & Jacobsson , 2003; Bergek, 2002; Carlsson & Stankiewicz, 1991; Carlsson, et al., 2002; Jacobsson & Bergek , 2004; Jacobsson & Johnson, 2000). In the Norwegian PV TIS, the establishment of international market created positive externalities with new firms entering the upstream level of the value chain. For these reasons, financial resources were allocated to the system, and private investors as well as venture capitalists (and Elkem) seized the opportunities to invest in the system (F6). As mentioned in the functional analysis, government did not guide the direction of search (F2). Nevertheless, institutional alignment created a space in which R&D instruments targeted at material technology were allocated to support activities in the PV system. As result, market and technological uncertainties were reduced, and external economies in form clusters started appearing in the system (F7).

Scholars also mentioned that allocation of resources is vital in the exploitation of economic of scale and market stimulation (Bergek & Jacobsson , 2003; Bergek, 2002; Carlsson & Stankiewicz, 1991; Carlsson, et al., 2002; Jacobsson & Bergek , 2004; Jacobsson & Johnson, 2000). This means that entrepreneurial experimentations, resource mobilisations and legitimation (Bergek , et al., 2008b; Bergek, et al., 2008a) must be stimulated in the growth of new TIS. In the Norwegian PV TIS, there were no specific mechanisms stimulating entrepreneurial activities. However, from the period between 2003 and 2008, policies instruments (SkatteFUNN, BIA and etc.) from the RCN and Innovation Norway were allocated to support knowledge development and entrepreneurial activities (F3). As institutional set-up aligned to support the system, new knowledge was spilled over from the offshore industry into downstream activities (F7). Consequently, new firms entered the downstream part of the value chain (F3), and expanded the collective knowledge of the system (F1).

Legitimacy was still low at this stage, because lack of political willingness and national vision (F5) hampered the formation of market (F4) in Norway. Development was triggered in 2008 from institutional framework due to Norway's target of reducing GHG emissions, and was governed by the central Government, which allocated R&D capital resources for the development of renewable technologies and environmental friendly technologies (F2). These instruments were also allocated to support R&D activities in the PV system and the formation of networks through R&D collaborations, which further helped stimulate knowledge development and diffusion (F1). As the upstream competence was strengthened, competitive advantage was achieved and the system was stabilised.

5.4.4 THE DECLINE PHASE

As illustrated in the functional analysis, negative feedback was triggered from external changes due to competition from china and the global financial crisis, which reduced government incentives in several countries. This led to unfavourable market conditions for Norwegian actors in 2009, leading the system into a decline phase.

At this stage, actors have recognised that they cannot compete on price at the international level. Instead, focus is placed on developing niche product. This period is being used to assess existing knowledge as well as exploiting niche products. The allocations of R&D resources in RENERGI and Solar United as well as the development of a common industrial strategy (Energy21) (F2) and the entering of new player players (F3) (with third generation technologies) are great indicators of belief in growth potential (F2). These mechanisms could stimulate R&D activities and the creation of new knowledge (F1).

6. DISCUSSIONS AND CONCLUSIONS

"We can't solve problems by using the same kind of thinking we used when we created them."

Albert Einstein

In this chapter, several elements will be discussed in respect to the research questions. First, the conditions under which the Norwegian PV TIS emerged shall be discussed. The issues discussed in regards to the first RQ will bring about the second RQ, which will discuss the position of Norwegian PV TIS in the international market and its effects on the development of the system. Third, major blocking mechanisms preventing the development of the system will be discussed as well as forces inducing the growth of the system. This will lead to the fourth RQ, which discuss the policy implications for dealing with the blocking mechanisms.

6.1 THE EMERGENCE OF THE NORWEGIAN PV TIS

RQ1: How has the Norwegian PV TIS emerged?

The answers to the first research questions have been touched upon during several part of chapter 5. However, this section will recapture the main contributing factors leading to the establishment of the system. In short, the Norwegian PV TIS emerged, due to several factors that made the transition from old industrial companies to new solar companies possible.

First, Norwegian PV TIS is largely based on the expertise and technology developed in Elkem and other companies in the metal, aluminium and process industry. Elkem is one of the world's largest producers of silicon. The company's explorative activities (F1) between late 1970s and 1980s laid the foundations for the knowledge required for producing silicon for the purpose of PV cells. During this period, Elkem has developed substantial amount of production and technological knowledge for the production of silicon cells. Through user-production interactions, Elkem was able to assess the opportunities and challenges of the PV market (*market knowledge*). Having assessed market opportunities, the company went through several explorative processes, by acquiring the necessary competence required to serve such market. With the acquisitions of Crystalox and Union crucibles in 1980s, the company was able to further explore metallurgical knowledge both in the production and characterisation of silicon and ferroalloy. These explorative activities laid the foundation for the production and technological knowledge required in producing wafers and silicon cells for PV purpose.

Second, in addition to Elkem's expertise in silicon field, increased global demand for silicon wafers in 1990s presented great market opportunities for Norwegian actors. This demand was a result of governmental policies in Japan, Germany, Spain, Italia, USA and other countries (*mechanism for market formation*). Alf Bjørseth seized the opportunity, and stands out as a central actor in the development of an industrial approach to wafer and silicon production in Norway. Bjørseth came from Hydro and Elkem before he was involved in starting up Scanwafer. With high demand in the global market, sales contracts secured access to private capital in Norway and in abroad. The story behind ScanWafer is an emblematic transitional process in terms of the technological processes and resources, which enabled the transition from old industrial companies into new industry. This leads to the third factors, which is the industrial revolution in Glomfjord involving the closure of old factories. The closure of Norsk Hydro's old production facilities in established industrial communities in Norway would lead to major downsizing in several part of the country.

In connection with the industrial revolution in Glomfjord, Reidar and Langmo started a wafer factory in Glomfjord. Taking over old industries has been decisive for the establishment of the first production activities (F6). This meant that there was guaranteed access to cooling water and relatively cheap hydropower, creating major competitive advantage for any Norwegian actors willing to produce wafer and silicon cells in Norway (F6). Furthermore, there were already established industrial parks in Glomfjord, Herøya and Årdal, allowing actors to benefit from the competence of established workforce with experience from a knowledge-based renewable energy and environment industry (F6 & F1). The establishment of the Norwegian PV TIS was therefore possible due to great interactions between Norsk Hydro, the local industrial park in Meløy and the competence of the two most important entrepreneurs, Alf Bjørseth and Reidar Langmo. Most importantly, Alf Bjørseth and Reidar Langmo's contributions in terms of technical, production, financial and commercial knowledge were crucial in allocating the necessary resources for major customers to articulate demand for the product (F2). The great relationships between industrial and financial actors have been decisive in terms of mobilising financial resources into the system (F6) in order to respond to demand from customers.

Finally, continuous improvement of the fully automated and optimized production systems allowed the creation of economic of scale and production value. Development of new technologies was conducted in collaborations with technology suppliers abroad and here in Norway, and helped improved production knowledge (F1). This is a great illustration of a transformation process, where the structural components and key functions influence each other in order to create feedback loops in the system.

6.2 NORWEGIAN TIS' POSITION IN THE INTERNATIONAL MARKET

RQ2: How has the international market influenced the growth of the Norwegian PV TIS?

A key indicator of how internationalized the Norwegian PV TIS is the localization of competitors and customers. Norwegian PV actors have over the years established themselves as some of the world's leaders in the manufacture of silicon and wafers, and recently in midstream and downstream activities. This could be considered surprising, considering the geographical location of the country and lack of domestic market. However, this industry has to some degree shown that abundant supply of raw materials combine with efficient use of technological expertise may be sufficient to break through on the international PV market, which some countries are willing to subsidize.

Both upstream and downstream actors have since the beginning of the system, targeted markets in Germany, Spain, Italy, USA and Japan. Long before production began in 1997, ScanWafer secured a major contract with several major international companies including Finnish Next Advanced Power Systems (NAPS), Japanese Melco and Dutch Shell Solar. Using Norwegian renewable energy for the production of solar materials, Norway has over the last 15 years managed to compete in the international market by exporting energy to other part of the world. In other words, the Norwegian PV TIS emerged to serve demand caused by policy initiative in several countries. In this development, few entrepreneurs were able to anticipate market growth, and seized the opportunities that emerged by building up new PV manufacturing industry from old industries.

This development is rooted in the knowledge of material science and silicon production, thereby allowing actors to build on existing competence. Soon, a number of upstream actors emerged, with varying degree of downstream and eventually midstream integration in the value chain. Essentially, entries of upstream players with leading position in the international market have not only strengthened upstream knowledge in the Norwegian PV TIS, but it has also helped strengthen the Norwegian supplier industry for solar industry, especially in the field of automation technology[66], but also for the delivery of various subcomponents materials.

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[66] For companies such as Molab as, Archtech as, Storøy Electrical, Bandak AS, Tronrud Engineering and BIS Production Partner

It is in the manufacture of silicon and silicon sheets for solar panels, so called wafers, that Norway is one of the leading international players, primarily through the locomotive REC, competing with giants such as German Sharp and Q cells and the Japanese Sanyo. Elkem Solar is another cornerstone of the Norwegian solar segment. The company has developed an energy efficient and cost effective process. This development has further spilled over to important technologies including the delivery of cutting fluid (Ekro As), reusable crucibles (CruSiN AS) and recycling of raw materials, such as recovery of severed from silicon ingots (Si Pro AS), recovery of waste from the intersection of silicon blocks (Metallkraft) and the cutting of fluid (Sic Processing AS) and repair of defective cells (Innotech As). Some of these actors have also become global players. In regards to cost reductions, Norwegian actors are well positioned to compete at in the international market through companies such as Metallkraft and Innotech Solar.

During the first few years, Metallkraft struggled to convince solar manufacturers of the benefits of recycling waste from the cutting process. The company revolutionised the industry when the PV industry was looking for ways to cut costs due high demand for silicon carbide and glycol. With such technology, it was possible to become a knowledge-based renewable industry environment. The company's next factory is located in Yangzhou, near Shanghai. The Chinese market is becoming increasingly important for solar manufacturers and suppliers. Several competitors of Metallkraft have emerged in China in recent years. In addition, Innotech is the only company in the world specializing in the production of solar cells from non-prime solar cells. The company's competitive advantage is based on the innovative technology behind the company's production. In Europe, they have strategic partnerships with the Q-Cells and Bosch Solar giving Innotech access to raw materials. In restoring the defective solar cells, Innotech help make PV more cost effective and environmentally friendly, and the company thus plays an important role in the industry's goal of reducing costs.

The emergence of the Norwegian PV innovation system is great illustration of an evolutionary process with a global reach. The system emerged to serve an increasing global demand, as results of policies from Germany, Italia, Spain and USA. Gradually, the PV industry began to mature, and maturation created new challenges, in which parts of the production chain is becoming more standardized. There is a constant pressure on companies in terms of being able to offer the most effective wafers. Some players favour from subsidies such as feed-in tariffs. The PV industry is therefore highly competitive in a highly internationalized market. International competition is tough, and a number of players from low-cost countries have entered the international market, driving down the price of PV cells. Essentially, the market for solar panels continues to grow with faster production capacity. With this, an oversupply situation emerged, leading to rapidly declining prices. Consequently, policymakers in countries such as Italy, Portugal and Spain are responding to these changes by lowering the incentive policies to match the low price levels. These changes have in turn led to the slower growth in 2011 and 2012.

While this decline provides unfavourable conditions for upstream actors, midstream and downstream actors are presented with great benefits. As such, in the upstream part of the value chain, competition will continue to be driven by cost factors leading to shifting production to low cost countries. These trends have emerged in Norway. Companies are forced to reduce production in order to get rid of the stock of solar panels that have built up in the recent past. Although industry players have turbulent times ahead, many are still optimistic and believe that there are grounds to preserve much of this industry in Norway. Going forward, it is in all probable that the Asian markets that will come to dominate. This is why many Norwegian companies are now establishing themselves in the Far East. For instance, REC moved the part of the production that could perform more cost-effectively to Singapore.

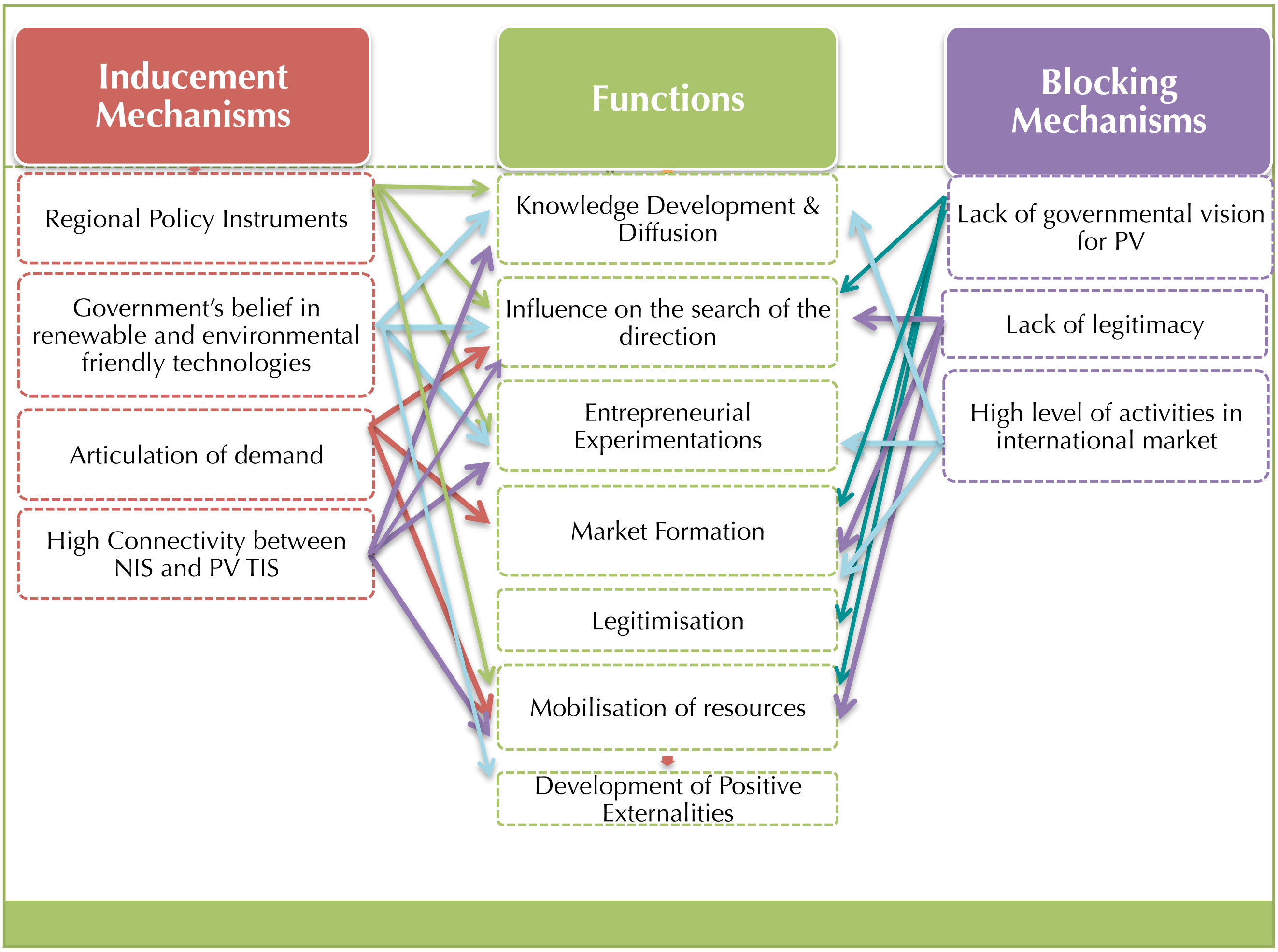
6.3 BLOCKING AND INDUCEMENT MECHANISMS

RQ3: What are the blocking and inducement mechanisms that have determined the development of the Norwegian PV TIS?

As mentioned in the introduction chapter, the global situation of fossil fuels dependency has created problems of 'carbon lock-in', obstructing renewable energy to become competitive. In the TIS framework, analysing the blocking and inducement mechanisms is essential for understanding the dynamics of internal and external sources, their interrelations within the system and how the operates to cope with the structural frameworks (and changes). As such, the blocking mechanisms are driven by structural elements, while inducement mechanisms are related to policy measures (Bergek, et al., 2008a). Insights into these mechanisms are essential for designing the appropriate policy measures that can deal effectively with these mechanisms in order to accelerate the diffusion process of the Norwegian PV TIS.

Having analysed and discussed the development as well as the functionality the Norwegian PV TIS, this section can now discuss the major blocking mechanisms hampering the development of the system and the mechanisms inducing the growth the system. As illustrated in figure 6.1, this will be done by illustrating how these mechanisms have influenced the seven functions in the system. These mechanisms have been derived from the strengths and weaknesses of the functional analysis as well as functionality and overall goals of the system. The figure shows that functional pattern is shaped by four inducement and three blocking mechanisms.

Figure 6.1 Blocking and Inducement Mechanisms in the Norwegian PV TIS



6.3.1 INDUCEMENT MECHANISMS

There are four significant inducement mechanisms shaping the development of the system. Two of these mechanisms (*Regional policy instruments and High connectivity between NIS and Norwegian PV TIS*) are driven by Norway's overall national approach to innovation and research. The last of two of the inducement mechanisms (*R&D policies promoting renewable and environmental technologies and articulation of demand*) are strongly linked to the target of cutting GHG emissions and government's belief in the importance of renewable energy sources.

1) Regional policies instruments targeted at regional and industrial development

The financial incentives provided to promote regional and industrial development were decisive for the establishment of the system. "The Norwegian Industrial and Regional Development Fund" (SND) was established in 1993, as a reorganisation of previously existing institutions was one of the main mechanisms inducing the development of the Norwegian PV TIS. The fund was established to promote socio-economic and industrial development at regional and national level.

During the period between 1994 and 2004, before merging into Innovation Norway, SND was one of the central actors for public funding for industrial and regional development in Norway, and contributed to the development of Norwegian PV TIS. During this period, its main supporters, the Ministry of Trade and Industry and the Ministry of Regional Affairs and Labour Relations provided financial grants and loans for innovation related activities and for other activities such as the development and acquisitions of new capital goods, warranties that enable firms to get loans from private financial institutions, and a general venture fund. These incentives were allocated to support the PV companies in the early high-risk period, and guided the search (F2). Funding was given on the conditions of market documentation and significant private participation. As such, the incentives from SND helped attracted other financial actors. As result, financial resources (F6) were also mobilised from private investors to support the production processes (F1), which in turn created favourable conditions for prime movers, and induced entrepreneurial experimentations (F3) in the upstream part of the value chain (and later downstream).

In addition to the contribution to the development of Norwegian trade and industry, SND's mandate also included the promotion of initiatives that provide employment in regions with unemployment problems. As part of these policies, funding was allocated to support education of employees, which in turn created positive feedback in mobilisation of [human] resources (F6). As more competent workforce were mobilised into the system, networks were expanded, and knowledge development and diffusion (F1) was induced. As result, new entrants with intermediate services and goods brought new type of knowledge that helped reduced production cost (F7), and increased the collective upstream knowledge of the system (F1).

2) Government's belief in renewable and environmental Technologies

This inducement mechanism is linked with government's attitudes towards renewable technologies as the solution of reducing Norway's target of GHG emissions. Government's belief in the renewable and environmental technologies can be viewed in two perspectives. First, Norway has traditionally been an energy-producing nation with abundance of hydropower. Government's ambition is for Norway to be at the forefront in Europe in regards to R&D in renewable technologies such as offshore wind, CO2 storage and hydro. Due to this increase national focus of RNE, access to complementary asset such as cheap hydroelectricity (F6) was a great input for knowledge development (F1), as it made it possible to produce in a cost effective manner, and created competitive advantage for Norwegian actors. Subsequently, demands from international customers were articulated (F2), which in turn helped improve actors' position (F5) in the international market.

Second, climate change has played a vital role in the management of the Norwegian energy system. The climate agreement from 2008 and Norway's target of 67.5 percent renewable energy by 2020 (The Ministry of Environment, 2011) in the EEA Renewable Energy Directive are further indications of the government's belief in renewable sources. Therefore, renewable and environmental friendly technologies as well as the implementation of smart and flexible technologies aiming at reducing energy consumption and emissions have been the focus in the country's energy policies. Essentially, the Government gives priority to research aimed at confronting the challenges related to energy supply and GHG emissions. As results, the Norwegian PV TIS profits from financial incentives targeted at R&D in the field of renewable and environmental friendly technologies (F2). For instance, between 2005 and 2011, NOK 150 million (The Research Council of Norway - RENERGI, 2011) was allocated to PV R&D activities through the RENERGI program, which promotes research activities within the field of renewable energy. These incentives provided a space where companies could develop scientific and technological knowledge (F1) in collaborations with universities and research institutes. Actors were hence motivated to experiment with PV, and the number of new entrants as well as the level of experimentations was diversified (F3). Subsequently, experimentations through networks led to the establishment of new companies (F7), which brought relevant competence that helped enhance upstream knowledge (F1). Last but not the least, the entering of new players combined with entrepreneurial experimentations reduced market, financial and technological uncertainties among actors and created cluster in the system (F7).

3) Articulation of demand from international customers

In addition to government belief in renewable and environmental technologies, the articulation of demand is another mechanism, which is connected to environmental concerns. First, the general concern for environmental issues has stimulated policies in several countries, which has increased the demand for PV cells. As results, international leading players have been great in articulating demand, which not only stimulate the market for Norwegian players (F4), and guided the direction of the search for both downstream and upstream players, but it also helped allocate financial incentives from SND (F2) and attracted private investors in investing in PV technology (F6).

4) High connectivity between NIS and the Norwegian PV TIS

The aforementioned mechanisms have been decisive for the development of the Norwegian PV TIS. However, high connectivity in terms of strong learning relationship between actors within the national system has also been significant in this development. First, there is a high connectivity between governmental agencies (IN, SIVA and NRC) and the PV industry. Due to this connection, existing frameworks (such as NYTEK, VAREMAT, and NANOMAT) targeted at Nano and material technologies as well as innovation related incentives (such as BIA and SkatteFUNN and other entrepreneurial incentives) guided the search of direction (F2) and enhanced scientific and technological knowledge of the system (F1).

Second, the high connectivity with these agencies has helped induced relationship between companies and research groups, and created strong learning networks (F1). This is mainly because R&D incentives were only provided to support PV activities with industrial potential (F2). Companies could hence develop scientific and technological knowledge (F1) in collaborations with research groups. Essentially, experimentations was increased (F3), and the PV industry has in collaboration with the research groups contributed to the development of several research groups with extensive knowledge across all part of the value chain (F1). Especially important is the IFE Kjeller, SINTEF and NTNU in Trondheim and the University of Oslo, UiA and Teknova in Kristiansand. Consequently, the development and creation of scientific and technological knowledge have been a significant factor in the success of the Norwegian PV TIS, because the transfer rate of the knowledge produced in the research communities into the PV system has been high.

Third, the high connectivity between the national system and the PV system has not only induced the development of knowledge and guided the search, but it has also mobilised [human] resources into the system (F6). For instance, during the period between 1994 and 2007, training involving processes of production optimisation and automation underpinned the development of the Norwegian PV companies. Education was thus significant for the success of the industry. The establishment of collaborations between start-up companies, technical and vocational schools as well local employment offices enhanced the training of employees and helped mobilised [human] resources (F6). The program run by these education offices provided a good generic knowledge base that contributed significantly to the introduction of a cost-effective production process (F1). In later phase of the system, research collaborations have been prerequisite for the development of new researchers, which forms a recruitment base for the industry (F6). Cooperation with Norwegian universities has contributed to the development of Master's courses oriented towards the PV industry. Most research projects are funded by the Research Council and co-funded by companies, leading to the education of doctoral candidates.

6.3.2 BLOCKING MECHANISMS

Two of the blocking mechanisms (Lack of government vision and lack of legitimacy) are connected to the fact that there has been an absence of support from national government in regards to national vision and policy supporting PV technologies. The third mechanism, which involves high level of activities in the international market, is also linked to the articulation of demand, which is discussed in the previous section as an inducement mechanism. There are clearly other blocking mechanisms, which have influenced the innovation processes. For instance, the main blocking mechanism during the pre-production phase is linked to a change in the institutional set-up. When energy prices fell in 1980, the level of experimentations gradually diminished (F3), because many actors become reluctant in experimenting with PV technology. Consequently, the level of public funding supporting RNE disappeared (F2), which resulted in the abortion of PV related R&D activities (F1). Nevertheless, the four mechanisms presented are the main mechanisms that block the development of the Norwegian PV TIS. All of these mechanisms emanated from lack of governmental initiatives.

1) Lack of governmental vision

The first major blocking mechanism is lack of governmental vision. The lack of vision of the role PV plays in the Norwegian energy system has blocked the development of the Norwegian PV TIS in several ways. First, the international market for PV technology is largely politically driven, through incentives such as R&D and FITs. A political development of new energy technologies makes long-term planning possible in countries such as Germany, Spain, Italy, USA and Japan. In Norway, the national government have not added up to a regime, in which PV can be supported through subsidies. This guided the search away from PV technology (F2). As long as there is lack of governmental vision, PV technology will continue to lack legitimacy (F5) in Norway.

Second, the lack of a governmental vision means that there are no policy measures and incentives (F2) supporting PV installation, which have led to an erratic demand and made it difficult to form a domestic market (F4). Norwegian PV manufacturers have thus been fully dependent on other countries' regulatory frameworks. Rather than stimulating market by facilitating more use of PV in Norway, the Norwegian funding agencies have guided the search by supporting PV related R&D

activities and by offering low electricity prices and infrastructure. Although, many industrial players have received financial support through governmental funding agencies, it should be noted that the extent of public support and involvement in this industry has been moderate compared to other European countries.

2) Lack of legitimacy

The second blocking mechanism is lack of legitimacy in the eyes of the Norwegian government. One contributing factor is that the Norwegian electricity consumption is dominated by hydroelectricity. Attentions are hence given to activities related to hydro technologies. Consequently, this have guided the search away from the PV technology (F2), which in turns block the mobilisation of resources for the diffusion of PV technology (F6) and obstruct the formation of a market in Norway (F4). However, lack of legitimacy is also the reason why Norwegian actors are operating in the international market.

3) High Level of activities in the international market

As mentioned in several part of this thesis, the Norwegian PV TIS emerged to serve a demand in the international market. Since PV lacks legitimacy in Norway, most of PV related products are exported and sold in other countries. Operating in an international market means greater exposure to economic, political, technological and sociocultural risks that have blocked the development of the Norwegian PV TIS. First, social economic changes in production capacity, as a result of supply of cheap PV cells from highly subsidized Chinese actors, has led to overcapacity and falling PV prices. Second, the financial and economic crisis has guided the search away from PV technology, and dismantled policy incentives for installing PV power plants in several European countries (F2), which have in turn lower the demand of solar cells in the international market (F4). Subsequently, knowledge development activities (F1) were blocked and entrepreneurial activities (F3) were obstructed, resulting in the closure of manufacturing plants and downsizing in Norway.

6.4 POLICY IMPLICATIONS

RQ4: How can the Government contribute to the development of the Norwegian PV TIS?

The overall purpose of this thesis is to understand the emergence of the Norwegian PV TIS, its diffusion as well as the mechanisms that promote or hamper its development. Having defined the process goals in section 5.4 and blocking and inducement mechanisms in the previous section, policy recommendations related to the blocking mechanisms will be discussed.

In order to accelerate the diffusion of the Norwegian PV TIS, it is essential that the Norwegian government takes the responsibility for implementing policy measures that will lead to a sustainable diffusion of PV technology in Norway. As illustrated in chapter 5, Norwegian actors have several competitive advantages in terms of knowledge and skills, which include expertise from the power market, metallurgical industries, process and material technology, petroleum, silicon and aluminium industries, maritime and offshore, all of which provide a solid foundation for developing core competence at all part of the value chain. It is therefore essential that the central government take the appropriate measures, so that Norwegian players exploit their competitive advantages while at the same time exploring new areas and moving to other part of the value chain. This means that policy measures must include the entire value chain, from knowledge of materials into finished products, and from basic research to the creation of new industries and incentives for market stimulation.

First and foremost, the central government must develop a national vision for the diffusion of PV technology. So far, lack of national vision has blocked legitimacy and the formation of a domestic market, which have in turn blocked the diffusion of the system. A national vision is hence essential for reducing the uncertainties surrounding the use of PV technology in Norway. This can open up a space for a change in legislation, which can accelerate the diffusion process. Such vision must solve the problem of developing a market for PV in Norway. For instance, the establishment of 1000 - roofs program in buildings, commercial and agricultural properties could be a great strategy for stimulating market. This can help attract both midstream and downstream actors into the system, increase expertise and help accelerate the use of PV in Norway. This type of program can also respond to the EU building regulations if necessary. The regulation has set targets that all new buildings must be "nearly zero energy" by 2020 and public buildings by 2017.

Although, there are currently schemes available for the diffusion of PV, they are not suitable for promoting PV technology in the construction market. For instance, the Surplus Plus Customer (see section 5.2.3.1) scheme allows people to use the power from their own solar panels without paying tariffs or consumption tax. The surplus electricity can be then sold to the network. The incentive is for end-users who produce electricity for self-consumption, and hence not suitable for the diffusion of PV in the construction market. PV can be also diffused through the "Green Certificates", which is a support scheme for renewable electricity for large plants. This kind of support applies only to deliver power to the grid, and the system must be approved by NVE. The green certificate scheme works well for wind power and hydro, and is a good policy tool for increasing renewable energy production. However, it is not particularly suitable for smaller plants and PV, because PV is small compared to what the certificate system is designed for. There is a thus a need for a governmental investment that could stimulate the market in way that can reduce price and increase demand. In doing so, the central government could establish a building integrated incentive through Enova. Experiences from Japan and Germany (see section 5.3.4) have shown that the price of installed PV drops rapidly when a market is established. With a functioning market and an increased awareness of PV technology, activities in the midstream and downstream part of the value chain will be strengthened.

Second, long-term conditions are important for both research and industrial development. Until now, the Norwegian PV TIS is aimed at the development of a knowledge-based industry in environmental technology. Essentially, the industrial development of PV in Norway occurred partly by harvesting technology from other industrial branches, and by allocating human expertise and skills in the process, production and material research. These strategic directions have enabled Norwegian actors to compete in the international market. Nevertheless, industrial maturity, an increasing degree of specialisation and strong international competition from low cost countries, point out the importance for directing attention toward segments of the value chain in which Norway has the greatest competitive advantages. The matter of the fact is that competing in the international market requires the support of a central government, leading a transformation process from the decline phase to a phase characterised by sustainable diffusion. To ensure such transformation, it is vital that the Norwegian central government takes the responsibility in implementing policy measures so that Norwegian companies operate with the same advantage as their international competitors. Such measures must allow Norwegian companies to maintain a technological competitive advantage by developing new technology, and mobilising human resources into the system.

In doing so, industry players, research council, agencies and educational and research institutions must continue to collaborate in developing skills relevant for the industry. The alteration of education can open a space for recruiting good candidates and remain competitive. In addition, the support for research and development of photovoltaic technology should be strengthened. Public investment in R&D is a very important factor for Norway to survive recession and compete on equal terms with low-cost countries such as China. It is apparent that Norway cannot compete on just cost. Norwegian players have a strong position in the production and processing of silicon, as the development of industry has been based on a substantial material competence. Therefore, Norway can play a significant role as a leader in PV technology, if emphasis is placed on these advantages.

This level of competence has been achieved through many years of expertise in the silicon and aluminium industries. An important prerequisite for the production of wafers and silicon cells has been long-term industrial power contracts. Production has led to a significant material and process expertise in education, R&D and manufacturing. The current development of the PV in Norway is based on this expertise, and the Norwegian actors have been competitive in the international market. Although low-cost countries now dominate the market, Norwegian upstream players may still have competitive advantage, because of their access to resources, technological expertise and experience. Ensuring adequate knowledge development in these areas is essential for developing niche products. Therefore, increased cooperation between industry players and research groups can open a space for niche products, and enhance the potential for success in the international market.

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APPENDICES

APPENDIX 1 – LIST OF INFORMANTS

ACTORS	INFORMANYS	PROFILE	DATE & PLACE OF INTERVIEW
Research institutes and universities			
SINTEF	Ingeborg Kaus	Ingeborg is Research leader at SINTEF.	Trondheim, 16.11.2012
	Mari Juel	Researcher at SINTEF and Manager for the Working Package on Mono- and multicrystalline at Solar United	Trondheim, 16.11.2012
IFE	Sean Erik Foss	Head of Department of Solar Energy and manager of the Work Package for Solar Cell and module technology at Solar United	Kjeller, 6. December 2012
NTNU	Turid Worren Reenaas	Research leader in the department of Physics in NTNU and WP Manager for Materials for NeXT generation solar cells at Solar United	Trondheim, 16.11.2012
	Gabriella Tranell	Gabriella is a research leaser in the Department material technology.	Trondheim, 16.11.2012
Teknova & UiA	Anne Gerd Imenes	Anne is a researcher at UiA and Teknova. I met her at the Solar Conference in Kristiansand in May 2012.	Skype, 21. December 2012
Industry Players			
Getek	Knut Erik Nilsen	Sales and marketing director at GETEK. He is also responsible for GETEK international.	Oslo, 15. November
Elkem As	Ragnar Tronstad	Director of R&D at Elkem and Elkem Sola and responsible of managing the Elkem research fund-EFF.	Skype, 30. November 2012
REC, Innotech Solar & Fusion AS	Thor Christian Tuv	Thor has previously worked at REC and Innotech Solar. He is now setting up his own PV power company in Akershus.	Oslo, 02. January 2013
Prediktor	Thomas Pettersen		Skype, 3. January 2013
NorSun	Alf Bjørseth	Founder of REC, NorSun, Scatec As, Scatec Solar and Scatec Power.	Oslo, 29. November 2012
Scatec AS	Ole Grimsrud	Ole is a Vice President of R&D. He has previously worked in REC	Oslo, 29. November 2012
Scatec Solar	Terje Osmundsen	Terje is responsible for strategic Projects involving international markets.	Oslo, 29. November 2012
Organisations			
The Norwegian Research Council	Anne Kjersti Fahlvik	Anne is staff member in the Innovation Department. She represented the Research Council in the working Group 6 – Innovation for Energi21.	Oslo, 7.december 2012
Innovation Norway	Tor Mühlbradt		Oslo, 20. December 2012
	Helle Moen	Department Manager, Brazil at IN. Former board member in Innotech Solar and Metallkraft.	Skype 29. November 2012
Enova	Sverre I. Heimdal		Trondheim, 16. November 2012
	Helle Grønli	Helle is a senior adviser in renewable heat.	Trondheim, 16. November 2012

APPENDIX 2 – INFORMATION AND CONSENT FORM

Tentative Title of study: Understanding the Development of the Norwegian Photovoltaic Industry
Type of study: Master Thesis
Student: Dede Koesah
Institution: University of Oslo, Centre for Technology, Innovation & Culture (TIK Senter)
Educational program: Master in Technology Innovation and Knowledge
Duration of Research: August 2012 – Mai 2013

Interviewee:

Background: My name is Dede Koesah, and I am student at the University of Oslo (UiO), where I study Master in Technology, Innovation and Knowledge at the TIK Centre. This is a two-year interdisciplinary master program that looks at various aspects of the production of knowledge in society, how knowledge and technology are created and used in business, politics and other areas of society.

I am writing my thesis on the Development of the Norwegian Photovoltaic Industry. The purpose of this study is to understand the development of the Norwegian Photovoltaic industry. The research seeks to provide an understanding of the processes involved in the formation and development of the Norwegian PV industry. The empirical data involves collecting and analysing information on how companies acquire and develop technologies, how research institutions develop technologies and how they collaborate with industry partners, how policy makers and other networks and research organisations contribute to the formation and development of the PV industry and technology. In doing so, structured and semi-structured interviews will be conducted with industrial partners including manufacturers, developers, financial partners, industry experts, researchers, government officials and policy makers.

Usage of information: The information gathered during the empirical process will be used for the analysis required to complete the Master Thesis. Upon completion, the study might be published internally at the University of Oslo, or externally, if the involved parties agree.

Participation: Participation involves being interviewed by Dede Koesah, the student at the TIK centre, University of Oslo. The interview will last approximately 45-90 minutes. Notes will be written during the interview. An audiotape of the interview and subsequent dialogue will be made.

Participation in this study is voluntary, and the interviewee is not obliged to take part in this study, and may decline to participate. This means that the interviewee may withdraw from the study at any time. If the interviewee decides to withdraw, the information provided will not be used in the thesis.

Participation in this study can be anonymous if the interviewee wishes to remain anonymous. The interviewer will take precautions to assure the privacy and confidentiality of the interviewee. If the interviewer chooses to use any quotes from an anonymous interview, the interviewee will be consulted in advance. The quotes will only be used if the interviewee consents.

The interviewee can ask questions about the research at any time, and may receive information about the research results and conclusions upon request.

I confirm that I have read and understand the information for the above study, and I agree to take part in the above study. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. ☐

I agree to the interview consultation being recorded on a tape ☐

______________________	______________	____________________
Name of Interviewer	Date	Signature

______________________	______________	____________________
Name of Interviewee	Date	Signature

APPENDIX 3 – INTERVIEW GUIDE

Bakgrunnsinformasjon: informanten

- ✓ Navn
- ✓ Tittel
- ✓ Utdanningsbakgrunn
- ✓ Arbeidserfaring/bakgrunn
- ✓ Hva er din stilling i selskapet?
- ✓ Når begynte du å jobbe i denne stillingen? Har noen motivasjon for å jobbe i denne bransjen?
- ✓ Kan du fortelle litt om GETEK?

Strukturelle komponenter – Aktører: Selskaper

1. Hvordan har bedriften utviklet den teknologien dere bruker? Hvordan får dere tilgang til relevant / ny kunnskap? Innoverer bedriften internt eller eksternt?
2. Hvorfor har bedriften valgt denne formen av innovasjonsstrategi? Og hva er de viktigste ulempene og fordelene av din innovasjonsstrategi?
3. Hvordan er strategier for de viktigste aktørene? Er den type strategi vanlig i industrien?*

Aktører: Forskningsinstitusjoner og Organisasjoner

1. Hvordan vil du karakterisere forholdet mellom næringsliv og forskningsinstitusjoner?
2. Hvilken rolle spiller forskningsinstitusjoner i utviklingen av den norske solcelle industrien? Er det noen relevante fagmiljøer som har eller vil påvirke utviklingen av industrien?
3. Hvordan har REC utvikling påvirket forskningsvirksomhet av i Getek?*

F1 - Utvikling og Diffusjon av kunnskap: Knowledge Development & Diffusion

1. Samarbeider dere med andre selskaper? I så fall hvem?
    a. Bedrifter
    b. Universiteter
    c. Forskningsorganisasjoner
    d. Andre?
2. Bruker bedriften lisenser, patenter eller andre immaterielle rettigheter i bransjen? Hva er effekten av lisenser, patenter og rettigheter? - Har dere noen patent eller noen spesiell lisens avtale om solcelle teknologien?
3. Får dere støtte knyttet til utvikling av solcelle? (Norsk Forskningsråd eller Innovasjon Norge?
    a. Fra hvilken organisasjon?
    b. Hva slags støtte?
    c. Hvis økonomisk støtte, hvor mye?
    d. Gjennom hvilken type program?
4. Hva er den samlede FoU-intensitet i selskapet? Hvor mye av de totale inntektene er brukt på FoU?
5. Fins det nok aktiviteter i industrien som fasiliteter utviklingen av kunnskap
6. Hva er kvaliteten på kunnskap i forhold til det internasjonale markedet?
7. Får solcelle teknologien spesiell oppmerksomhet i nasjonale programmer?*

F6 - Ressursallokering: Resource Allocation

1. Hva er de viktigste kildene til bedriften ressurser i form av kapital?
2. Hvordan og hvor er ressursene fordelt?
    - Menneskelige ressurser
    - Finansieringsressurser
    - Produksjonskapasitet
    - Teknologisk utvikling
    - Venture kapital
    - Logistikk kapasitet
3. Hvordan blir disse ressursene brukt?
    a. FoU
    b. Pilotprosjekter / eksperimenter
    c. Utdanning
    d. Implementering

Industri Bakgrunn og profil - Informasjon om industrien

1. Hvem er de store aktørene i industrien?
2. Hvem var de pådriverne (viktige aktører) i de siste 5-10 årene? Og hvordan har deres bidrag påvirket industrien?
3. Hvordan har industrien utviklet seg i løpet av de siste 5-10 årene?
4. Hva er de største elementer som blokkerer industriell (teknologiske) utvikling?
5. I din mening, hva har vært de viktigste faktorer som kan bidra til for utvikling av solcelle industrien i Norge?
6. Kan Norge se på andre nasjoner for inspirasjon? Hvilke nasjoner og hvorfor?

Nettverk - Læring og informasjonsutveksling

1. Har det kommet nye aktører i bransjen i løpet av de siste 5 – 10 årene?
2. Har disse aktørene bidratt til kunnskapsutvikling i industrien? Har de påvirket makt dynamikken i bransjen?

F7 - Positive eksternaliteter: Positive Externalities

1. Har nye aktører forsterket (eller programmer) utforming av markedet?
2. Har nye aktører tatt med nye arbeidskraft i industrien?
3. Hva er rollen til eksisterende arbeidskraft? dvs. incumbents
4. Hva har blitt gjort for å redusere usikkerhet blant aktørene?

Nettverk - Læring og informasjonsutveksling

1. Er det noen formelle eller uformelle fora som skaper mulighetene for utveksling av kunnskap? Hvis ja, hvordan har dette blitt oppnådd?
2. Deltar bedriften i noen nettverksfora? Hvis ja, hva slags nettverk? Og hva er bedriftens forventninger i forhold til disse nettverkene?
3. Har internasjonale selskaper spilt noen roller for utviklingen av den norske solcelle industrien/ eller GETEK?

F7 - Positive eksternaliteter: Positive Externalities

1. Hvordan er informasjonsdynamikken og kunnskapsflyt mellom industri og politiske aktører?
2. Har aktørene noen ambisjoner eller forventninger for internasjonal utvikling?
3. Hvilke aktører er involvert i kommersialisering av PV-teknologi?
4. Hva har blitt gjort for å redusere usikkerhet blant aktørene?
5. Hva er rollen til eksisterende arbeidskraft? dvs. incumbents
6. Har nye aktører tatt med nye arbeidskraft i industrien?
7. Har nye aktører forsterket disse forsterket (eller programmer) utforming av markedet?

8. Hvordan er politisk makt mellom aktørene?

F3 - Entreprenør eksperimenter: Entrepreneurial Experimentations

1. Er det forskjellige typer applikasjoner i markedet? Må bedrifter fokuserer på spesifikke markeder i Norge?
2. I hvilken grad, driver gründere, bedrifter og forsker forskning?
3. Hva er de teknologiske forventninger blant de store aktørene og politikere?
4. Tror du disse forventningene påvirker endringsprosessen?
5. Er det forskjellige typer applikasjoner i markedet? Må bedrifter fokuserer på spesifikke markeder i Norge?

F4 - Utforming av Markedet: Market Formation

1. Hva er størrelsen på markedet? – Øker markedsandelen?
2. Hvilke faktorer har drevet utforming av PV-markedet?
3. Hva har blitt gjort for å stimulere utforming av den norske solcelle markedet?
4. Hva synes du om feed-in tariff markedet?
5. Hvem er de viktigste brukerne / forbrukere? Er disse brukerne fra offentlig eller privat sektoren?
6. Hvordan kommuniserer bedriften/ med brukerne? Er denne formen av kommunikasjon vanlig i markedet?
7. Hvordan tar du investeringsbeslutninger i bygging av solkraftverk?*
8. Hvordan er innkjøpsprosessen (og makt) innen markedet?
9. Hvilken institusjonelle/politiske faktorer har påvirket markedets utforming?

Aktører: Institusjoner

1. Hva er de viktigste regulering i den norske PV industrien?
2. Hvordan har disse retningslinjene påvirket bransjen?
3. Hva er standard i bransjen? - Er det spesielle standarder skreddersydd for solcelle-industrien?

F2 - Innflytelse på retningen av søket: Influence on the direction of the search

1. Ha regjeringen satt konkrete mål for utvikling og diffusjon av solceller?
2. Hvis ja, er disse målene støttes av noen virkemidler?
3. Støtte viktige aktører i bransjen disse målene?
4. Hvem er motstanderne av solcelle teknologien? Og hva deres (har du noen eksempler) handlinger og strategier?
5. Tror du regjeringen må implementere spesifikke lover rettet mot solcelle industrien for å stimulere utvikling?

F5 - Legitimering: Legitimation

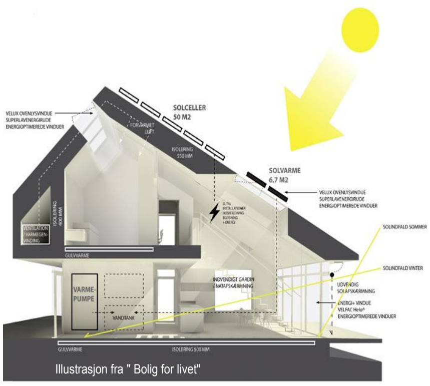
1. Er det noen institusjonelle/politiske prosesser som har bidratt til positiv eller negativ utvikling?
2. Når begynte disse prosessene og hvem er de viktigste bidragsytere?
3. Er det noen interessegrupper som er mot disse endringene?
4. Er det grupper som driver lobbyvirksomhet for solcelle? I så fall hvem er aktørene som er involvert i disse gruppene?

Industri Bakgrunn og profil - Industri Outlook

1. Hva er de viktigste utfordringene for de neste 5 årene?
2. Hva er dine forventninger i forhold til utviklingen av teknologi og marked?
3. Hva er de mest kritiske barrierer for denne utviklingen?
4. Tror du den norske solcelle industrien kan være konkurransedyktig i internasjonalt markedet?
5. Tror du RECs nedgang vil påvirke norsk PV industrien eller det norske markedet? I så fall, hvordan?

APPENDIX 4 – PROGRAM FROM SOLAR CONFERENCE IN OSLO

**** SOLENERGIDAGEN 4. MAI 2012 ****



Illustrasjon fra " Bolig for livet"

SOLENERGI I PRAKSIS

Betingelsene for og kunnskapene i å ta i bruk solenergi har nå nådd et nivå der det er realistisk å anvende den i bygg.
Solenergidagen 2012 vil derfor fokusere spesielt på praktisk bruk av solenergi, og erfaringer fra realiserte prosjekter i drift i Norden.

Norsk solenergiforening - www.solenergi.no

European Solar Days

PROGRAM SOLENERGIDAGEN 2012

09.30	Registrering og kaffe
10.00	Velkommen v/ Åse Lekang Sørensen, Generalsekretær Norsk solenergiforening
10.10	PV (solstrøm) – dagens status og framtidens muligheter v/ Ole Grimsrud, Vice President Research & Development, Scatec AS
10.35	Termisk solenergis framtid i Norge og verden v/ John Rekstad, Professor Fysisk institutt UiO
11.00	Kaffepause
11.20	Bolig for livet, Danmark – observasjoner og målinger Fra et bebodd aktivhus med bruk av solenergi v/ Tommi Haferbier Nielsen, Esbensen Rådgivender Ingeniører, Danmark
11.50	Form følger miljø - Powerhouse-alliansens to første prosjekter v/ seniorarkitekt Tine Hegli, Snøhetta
12.15	Lunsj
13.00	Oseana - fra planer til driftserfaringer fra Norges hittil største solcelleanlegg v/ Knut Erik Nilsen, Marketing Director, Getek AS
13.25	Salg av overskudd av egenprodusert strøm til nettet Norges første plusskunde - erfaringer med sol og motstrøm v/ Kjell Eikland, EVRY, Hafslunds plusskunde med kommentarer fra Hafslund v/ Elvedin Grudic
13.55	EnergyFlexHouse, - Teknologisk Institut, Danmark Kort visning av energilog på nett fra to sol / aktivhus i bruk v/ Norsk solenergiforening
14.00	Kaffepause, småprat
14.30	Solenergi - hvorfor og hvordan? - vyer, prosjekter og bygg v/ Daniel Kjørberg Siraj, administrerende direktør OBOS Nye Hjem AS
14.50	Interessen for solenergi vokser Opplæring av utførende og konsulenter i Norge og Sverige v/ Lars Andrén, Svensk solenergiforening
15.15	Veien videre – hva må gjøres? - Plenum
15.30	Slutt

SOLENERGIDAGEN 2012 - SOLENERGI I PRAKSIS

Solenergidagen er arrangert av Norsk solenergiforening, og er et ledd i European Solar Days. I perioden 1. til 13. mai gjennomføres mange solenergiarrangementer i Norge så vel som ellers i Europa. Norske arrangementer, se: www.solenergi.no/ESD2012.

NORSK SOLENERGIFORENING

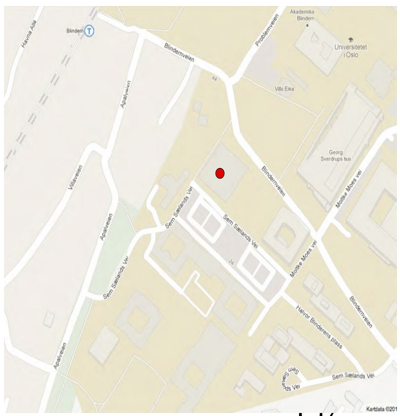
Norsk solenergiforenings formål er å fremme økt bruk og kunnskap om solenergi i Norge, og favner alle som ser potensialet bruk av solenergi representerer.

PÅMELDING

Påmelding til www.solenergi.no/solenergidagen2012/
Gi beskjed ved behov for parkeringsoblat (utdeles ved registrering)
Deltakeravgift (medlem / ikke medlem i Norsk solenergiforening):
400kr / 900 kr (personlig medlemskap 500 kr i året)
Studenter: 50kr / 100kr (personlig medlemskap 50 kr i året

STED

Helga Engs hus, auditorium 1
Universitetet i Oslo - Blindern
Sem Sælands vei 7
Trikk 17 eller 18 mot Rikshospitalet
T-bane 3,4,5 eller 6 til Blindern



APPENDIX 5 – PROGRAM FROM SOLAR CONFERENCE IN KRISTIANSAND

PROGRAM

08.00 - 08.30 Registration and coffee

WELCOME & INTRODUCTORY TALKS: Political and Market Development

- **Arvid Grundekjøn, Mayor of Kristiansand**
  "Welcome"
- **Alf Egil Holmelid, Member of Parliament**
  "Solar industry between markets and politics"
- **Signe Antvorskov Krag, Gaia Solar & Danish Solar Cell Association**
  "PV politics and market development in Denmark"
- **Terje Osmundsen, Scatec Solar**
  "The next wave for PV: Solar power meet grid-parity"

10.00 - 10.15 Coffee break

TECHNICAL SESSION I: Technology Developments in Photovoltaics

- **Erik Stensrud Marstein, Institute for Energy Technology**
  "How solar cells are changing the world – solar energy today and tomorrow."
- **Tom Markvart, University of Southampton**
  "Harvesting Sunshine: From Solar Cells to Artificial Photosynthesis"
- **Turid Reenaas, Norwegian University of Science and Technology**
  "3rd generation solar cell research in Norway"
- **Ole-Morten Midtgård, University of Agder**
  "Performance testing of photovoltaic modules in Southern Norway"

11.45 - 12.45 Lunch

TECHNICAL SESSION II: Photovoltaic Application and Integration

- **Jörg Bagdahn, Fraunhofer CSP**
  "Photovoltaic modules: Current status, further trends and reliability issues"
- **Jan von Appen, Fraunhofer IWES**
  "Preparing for high penetration of photovoltaic systems in the grid".
- **Tine Hegli, Snøhetta Architecture**
  "State of the art building design; solutions and markets for integration of photovoltaic technology."
- **Kjetil Rostoft Boysen, Eltek**
  "Smart grid and grid-connection of PV systems".

14.30 - 14.45 Coffee break

INVESTMENT & MARKET SESSION: Finance and Industry

- **Erik Edvard Tønnesen, Skagerak Venture Capital**
  "A European industry overtaken by China?"
- **Ragnar Tronstad, Elkem Solar**
  "Norwegian companies show pioneer spirit in solar technology – but will the industry have a future in Norway?"
- **Yngve Walle, Pareto**
  "Developments in the equity and debt markets - from a solar industry perspective"
- **Lars Bjørn Christiansen, Nordea**
  "Bankability within the solar industry"

- **Anne Gerd Imenes, Teknova & University of Agder**
  "IEA PVPS Task 13 : Performance and Reliability of Photovoltaic Systems"
- **Concluding remarks**

16.15 End