# ANALYSIS OF THE INNOVATION SYSTEMS OF PHOTOVOLTAIC TECHNOLOGIES IN THE NETHERLANDS

*Thesis submitted in partial fulfillment of the requirements for the degree of*

MASTER OF SCIENCE IN MANAGEMENT OF TECHNOLOGY


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Tarak Jabri,

Leidschendam, 2011

# Table of Contents

# Executive summary

Environmental problems and the dependence on fossil fuels led to increasing interest in renewable energy sources. Photovoltaic (PV) technologies can convert the light emitted by the sun directly into electrical energy. Therefore PV technologies are very promising and the expectations are high worldwide.

Compared to neighboring countries like Germany, the installed capacity of PV in the Netherlands is disappointingly low. This is striking considering the high expectations regarding PV. This means that there is still a lot to be changed and developed regarding these technologies.

There are different PV technologies, each in a different phase of development and having different specs. Since PV technologies are emerging technologies, a lot can still change. It would be interesting to assess which of the PV technologies is playing or will play an important role in the way towards sustainable energy production in the Netherlands.

To do the assessment, the following research question needs to be answered: *"What factors of the Innovation System of PV technologies boost or hamper their development and diffusion in the Netherlands and how did that affect the competition between them? ".*

To answer that question the following technologies have been chosen: Crystalline silicon solar cells; thin film silicon solar cells; CIGS and CIS solar cells; CdTe solar cells; and organic solar cells.

To analyze the factors that boost or hamper the development and diffusions of the technologies, their Technology Specific Innovation System (TSIS) is going to be analyzed. A TSIS 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). The TSIS will be analyzed using 7 Functions of Innovation Systems (FIS). Each of these functions assesses a part of the TSIS of the technologies. The functions are

- Entrepreneurial activity [F1]
- Knowledge development [F2]
- Knowledge diffusion through networks [F3]
- Guidance of the search [F4]
- Market formation [F5]
- Resource mobilization [F6]
- Creation of legitimacy/ counteract resistance to change [F7]

Indicators of each function are described in Table 2.1 in chapter 2. The interaction between the functions will then be analyzed using motors of innovation. These motors of innovation describe several vicious and virtuous cycles or a follow up of events that influenced the development and diffusion of the PV technologies.

The research showed that most of the technologies showed so called motors of Science and Technology Push (STP). This motor of innovation is characterized by being dominated by the functions Knowledge development [F2], Knowledge diffusion through networks [F3], Guidance of the search [F4] and Resource mobilization [F6]. Entrepreneurial activities [F1] are weak or even absent. Only CdTe cells showed motors of decline or vicious cycles because the use of cadmium of prohibited when used in combination with some other materials. CdTe is the only technology on which no research is done in the Netherlands nor has there been any entrepreneurial activity, except for machine manufacturing.

Not many entrepreneurial activities have led to the actual diffusion of solar cells in the Netherlands. Most entrepreneurial activities only boosted the knowledge developed within the country. Machine manufacturing companies are an example of these entrepreneurs.

Entrepreneurial activity that leads to diffusion of the technology was only identified for crystalline silicon cells. These cells were first in being ready to be marketed. Between 1985 and 2003, a lot of demonstration projects took place. The EPR subsidy also encouraged users to acquire crystalline silicon PV systems. Therefore an Entrepreneurial motor was identified for crystalline silicon cells between 1985 and 2003. This is when an STP motor "evolves" and more entrepreneurial activity and demonstration projects take place. This would then improve the expectations regarding the technology. However, because the government was still hesitative and entrepreneurs were mostly focused on export, there was no steady subsidy scheme which was needed regarding the high costs of a PV system. This led to a downfall in demand and the Entrepreneurial motor fell back to a STP motor.

Thin film silicon was researched almost as much as c-Si. Diffusion of this technology however did not take off. International disappointing results decreased the interest of investors in thin film silicon. This resulted in the closure of the only company involved in this technology, Helianthos. They had a pilot plant for years and never actually started large scale production. CIGS have not really been a subject of research very often. This was mostly because the technology used scarce materials. However the fast international developments regarding this technology led to more research activities and collaboration between Dutch players within the PV TSIS in the Netherlands. There are many actors with different skills, they are now bundling their knowledge to exploit the growing CIGS market. Organic PV is receiving a lot of attention from universities and research institutes. Especially polymer cells are profiting from the fast developments of organic electronics. Production has not taken off yet in the Netherlands because the technology still needs a lot of developments. Investors have therefore still not invested in any production plant.

The government has not played a big role in determining which technology acquired the strongest TSIS. Subsidies and regulation were actually the same for each of the technologies. Technologies were researched at different universities and institutes, and if one started a research on a new technology they did not abandon their old research. The competition between the technologies was mostly the result of international factors. These are factors like international research results, availability of raw material and international demand. Entrepreneurs in the Netherlands were therefore mostly driven by export and investors also based their investment decisions on international factors. CdTe for example was not so popular in the Netherlands but internationally it is the most successful thin film technology. Therefore the slower developing thin film silicon in the Netherlands was not so interesting for investors.

The analysis of TSIS using FIS was found to lack the attention to international factors. Even when considered their role seems being undermined because they are spread among different functions. This thesis therefore recommended collecting these international factors in a separate function. This function has a lot of influence on the other 7 functions of FIS but not the other way around.

# Glossary

A-Si: Amorphous silicon

BIPV: Building Integrated Photovoltaics

BOS: Balance Of the System

C-Si: crystalline silicon

CdTe: Cadmium telluride

CIS: Copper indium diselinide

CIGS: Copper indium gallium diselide

CI(G)S: Copper indium (Gallium) diselinide

ECN: Energieonderzoek Centrum Nederland

EET: Economy, Ecology and Technology program

EOS: A government financed R&D program

EPA: Energy Performance Assessment

EPR: "Energie Premie Regeling" subsidy to refund costs for investments in sustainable energy

ETP-CVD: Expanded Thermal Plasma – Chemical Vapor Deposition

FIS: Function of Innovation System

FOM: Foundation for Fundamental research on

GWh: Giga Watt Hour

GaAs: Gallium Arsenide

GW: Giga Watt

IS: Innovation System

KW: Kilo Watt

KWh: Kilo Watt Hour

KWp: Kilo Watt Peak

LTS: Large Technical System

MAP: Environmental Action Plan of companies

MEP: A subsidy program

MW: Mega Watt

MWh: Mega Watt Hour

NOZ: National Solar Energy Program

NSI: National System of Innovation

NWO: The Netherlands Organization for Scientific

OLED: Organic Light Emitting Diode

OPV: organic photovoltaics

PUM: Pin Up Module

PV: Photovoltaic

R&D: Research and Development

RGS: Ribbon Growth on Substrate

SDE: "Stimulering Duurzame Energieproductie" a subsidy program for sustainable energy

SES: A subsidy program for sustainable energy

SiN: Silicon nitride

SSI: Sectoral System of Innovation

STP: Science and Technology Push

TCO: Transparent Conductive Oxide

TF-Si: Thin film Silicon

TSIS: Technology Specific Innovation System

VAMIL: Tax refund to stimulate sustainable energy use

W: Watt

Wp: Watt peak

# 1. Introduction

## 1.1 Research problem

Fluctuating fossil fuel prices and high CO2 emissions call for renewable energy sources. Many of these renewable energy sources successfully found their way to the energy market and are used more and more (Herzog, 2004). Photovoltaic (PV) technologies, used for the direct conversion of sunlight into electricity, are very promising providers of energy in the future (Green, 2000). The main advantages of these technologies are that it can produce electricity without emissions, moving parts or noise (Hoffman, 2006).

Photovoltaics were at their introduction used for space applications like satellites. During the seventies it started to be used in terrestrial applications especially for the telecommunication industry (Oliver, 1999). It used to power relay and repeater stations and telephones in remote areas. In the Netherlands it began to be considered as an interesting candidate for renewable energy during the nineties. Ideas to connect PV's to the grid were already the subject of many projects during the eighties but the high prices were a major obstacle (Verbong, 2001).

The idea of applying Photovoltaics in the Netherlands started around 1974 (Negro, 2008). In 2007, the share of renewable energy sources in electricity generation represented 6.1% producing 7372 GWh. PV only produced 36 GWh in 2007 (Rosende, 2010) meaning that it represents only 0.5% of the renewable energy and 0.0003% of the total energy produced in the Netherlands.

There are many different PV technologies, each of them at a different stage of development (in terms of efficiency, reliability etc.) and each having their advantages and disadvantages. This must create different views and expectations amongst actors involved in this technology.

As the share of Photovoltaics in energy generation in the Netherlands is so minuscule, there is still a lot of development to be done and a lot of obstacles to overcome. Therefore, the factors that can hinder or boost the development and diffusion of PV technologies need to be analyzed in order to assess which of these PV technologies will play a significant role in the transition towards sustainable energy production in the Netherlands.

## 1.2 Research goal

A frequently used framework to analyze factors that hinder or boost the development and diffusion of a technology is the Functions of Innovation Systems framework (Kamp, 2010). This framework is explained in more detail in chapter 3.

An Innovation System (IS) or System of Innovation is the ensemble of determinants of an innovation process. All important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations (Edquist, 2004).

The term innovation can be divided into two kinds: product innovation and process innovation (Edquist, 2004). Product innovations are new or better material goods as well as new intangible services. Process innovations are new ways of producing goods and services. They may be technological or organizational.

Several researches have been done regarding the Dutch PV Innovation System ((Kamp, 2009),(Prent, 2008),(Negro, 2008)). The researches done on PV in the Netherlands concentrated on the overall situation regarding the development and diffusion of PV. The conclusions are mainly that institutional factors are hampering the development and diffusion of Photovoltaics in the Netherlands. Low subsidies and lock-in of fossil fuels make the PV market risky and unstable. Research done at the TU Delft concerning the PV innovation systems in Japan (Prent, 2008) considered different PV technologies separately. This led to interesting results, showing that each PV technology in Japan has its own IS and its success is therefore different than the other technologies available. Research on the IS of each PV technology in the Netherlands is not done yet.

The difference between this research and researches done in the past is that this research will focus on the Innovation Systems of different PV technologies that are used and developed in case of the Netherlands. This way it can be investigated whether the barriers found in previous researches hold for the IS of each PV technology in the Netherlands. The research will explore whether the competition between the Innovation Systems of the different PV technologies is hindering the development and diffusion of Photovoltaics in general. The research can also give an indication about which PV technology has the most potential in the Netherlands; and for what reasons.

## 1.3 Research questions

This thesis is intending to answer the following main research question: *"What factors of the Innovation System of PV technologies boost or hamper their development and diffusion in the Netherlands and how did that affect the competition between them? "*

To get closer to the answer of the main question, the following sub-questions need to be answered:

- "What are the available PV technologies that are being used and developed in the Netherlands?"

- What are the available theoretical frameworks to analyze the development and diffusion of technologies?

- Which framework is most suitable to analyze the development and diffusion in the case of PV technologies in the Netherlands?

- "Using the chosen framework, how has the development and diffusion of each technology evolved in case of the Netherlands since 1974?"

- "Is the chosen framework suitable to analyze the competition between technologies that serve the same purpose?" In this case Photovoltaic technologies.

## 1.4 Selected PV technologies

This paragraph will first explain for which applications the PV technologies are going to be investigated. Then paragraph 1.4.2 will go into details of the principles of Photovoltaics and which technologies are going to be investigated in this thesis. The last part of this paragraph will also go into detail about the price of PV.

### *1.4.1 Purpose of the selected PV technologies*

Solar cells can be used for different applications, from power supply of small electronic devices to the power supply of entire buildings or neighborhoods. The selected purposes in this thesis are related to domestic and industrial power supply (IEA, 2006):

**Off-grid domestic PV power system**

These are Systems installed to provide power mainly to a household or village not connected to the main utility grid. These systems are also called "Stand alone PV power systems".

**Off-grid non-domestic PV power system**

These systems are used for a variety of industrial and agricultural applications such as water pumping or remote communication technologies. These systems are also stand-alone and are not connected to the main utility grid

**Grid-connected distributed PV power system**

These systems provide electricity to grid-connected customers or directly to the electricity grid. Such systems are usually integrated into the customers' premises, houses and on public and commercial buildings. They may be specifically designed for the support of the utility distribution grid.

**Grid-connected centralized PV power system**

These power production systems perform the function of centralized power stations. The power supplied by such a system is not associated with a particular electricity customer.

### *1.4.2 The PV technologies*

#### *The principles of Photovoltaics*

Photovoltaics or Solar cells work on the principle of the Photovoltaic effect. This effect entails that at the junction of two semiconductor materials, a voltage difference can be measured under influence of illumination (Green, 2000). In Figure 2 the basic principles are illustrated. The material used in general is Silicon. "Doping" of this material with atoms from other materials leads to the creation of two kinds of semiconductors. N-type semiconductors, where electrons are the main energy carriers, and P-type semiconductors, where holes are the main energy carriers (Luque, 2003). Holes can be considered as positively charged energy carriers, unlike electrons which are negatively charged.

Under influence of the energy of photons in light, electrons and holes are released in the material and the electrons move through an external wire to an electrical load.

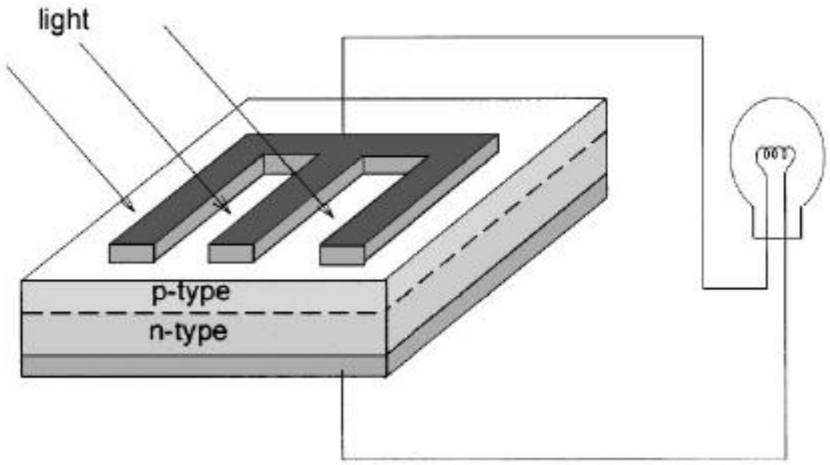


**Figure 1.1: Schematic overview of PV operation (Green, 2000)**

There are several different technologies when it comes to Photovoltaics or solar cells. The technologies that are now available on the market are Silicon based Solar cells and non-Silicon based thin film solar cells (Raugei, 2009). Other solar cell technologies that have not really left the laboratories yet are organic solar cells.

### *Available technologies*

Figure 1.2 shows the market share of the most popular PV technologies. The remaining of this paragraph will explain which technologies are going to be considered for this thesis. This is done by first dividing the cells in two groups: Silicon based solar cells and non-Silicon solar cells.

#### ***Silicon based solar cells***

Silicon based solar cells dominate the world PV market today (Rubin, 2010). Silicon can be made out of quartz or just sand (Green, 2000). Silicon is also a basic material for microelectronics. Therefore, the PV industry can benefit from the already existing Silicon production technologies. Since the Silicon for solar cells does not need to be as pure as the Silicon needed for microelectronics, the “Off-specification” Silicon from the microelectronics industry can be used in the PV industry. The production techniques of Silicon are quite expensive which lead to the high prices of solar cells based on Silicon. In fact, the costs related to the production of Silicon represent about 50% of the total costs of a PV module. Figure 1.3 depicts the costs of Silicon compared to other costs to produce PV modules. Solar cells made with silicon are usually wafers which are sawed out of crystalline silicon ingots (Figure 1.4), but there are also thin film technologies which do not have to be made in wafer form.

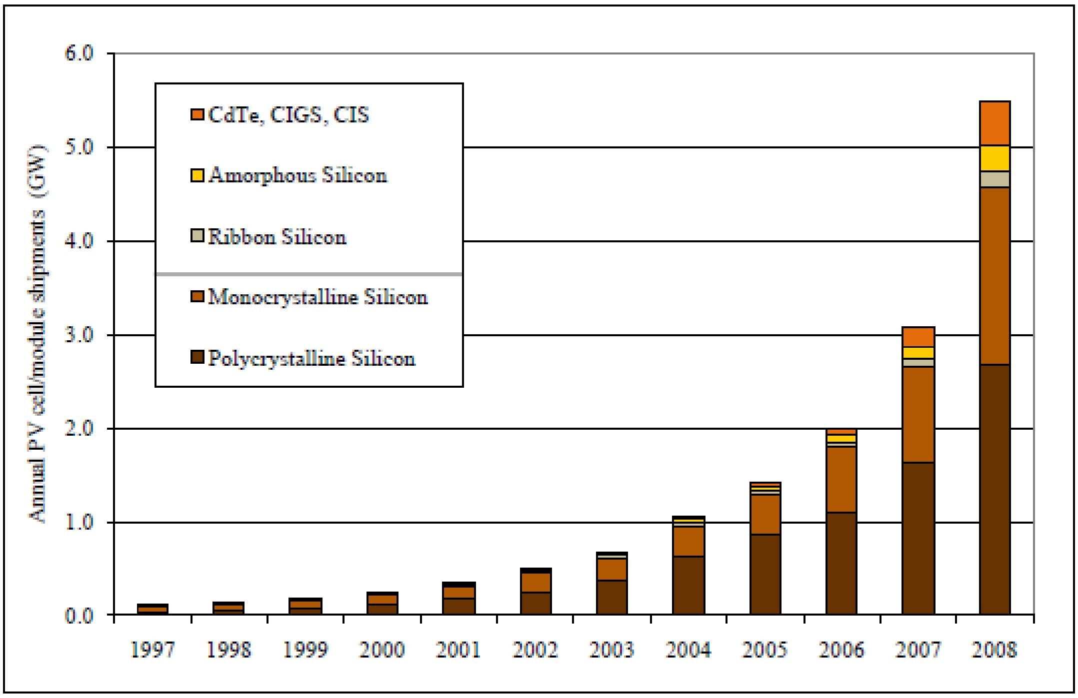


**Figure 1.2: Global annual PV cell/module shipments by PV technology (U.S department of energy, 2008)**

### Mono Crystalline Silicon solar cells

These are the most reliable and efficient solar cells on the market today. The laboratory efficiency of these cells, under perfect conditions, is about 25%. The commercial modules have efficiencies of about 13 to 16% (ECN, 2010).

### Polycrystalline silicon solar cells

The silicon used for polycrystalline silicon, also called multi crystalline silicon, is of lower quality than mono crystalline silicon. The wafers made of polycrystalline silicon contain more impurities than mono crystalline silicon (Rubin, 2010). This makes polycrystalline silicon solar cells slightly less efficient (14% for commercial modules). However, it is also cheaper than mono crystalline solar cells (see Table 1.1).

### Ribbon Silicon solar cells

Mono and poly (multi) Crystalline Silicon wafers are made by first cutting a bulk of Silicon into wafers. Cutting these bulks comes with a price and a lot of material is wasted as sawdust. As a cost cutting alternative, the idea of Ribbon Silicon was created. This way the melted silicon is directly poured in the form of a wafer, and hence sawing waste is saved. The resulting wafers are multi-crystalline but they have a lower efficiency than regular multi crystalline silicon cells made out of wafers (Weeber, 2011). Because these cells are in fact multi-crystalline silicon, they will be considered as such in this thesis and they will not be separately investigated.

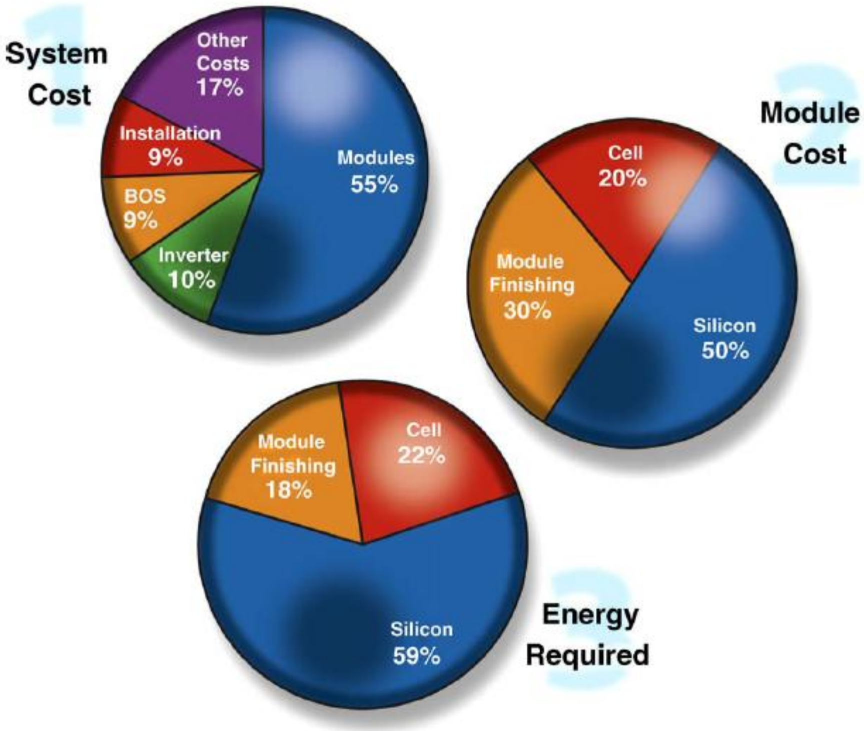


**Figure1.3: Overview of the costs to make a PV module ( Kazmerski, 2005)**

### Thin film silicon solar cells

Next to the crystalline silicon cells made in the form of wafers, there are also thin film silicon solar cells which are directly damped on a flexible substrate or superstrate (glass) and therefore do not have to be sawed from ingots (Birkmire, 2010). The most common thin film silicon technologies are:

***Amorphous Silicon solar cells***

These cells have an efficiency of approximately 6-8% and are on the market since 1980 (Birmkmire, 2010).

***Micro-crystalline silicon solar cells***

The production technology for micro crystalline silicon cells is about the same as that of amorphous silicon (Birkmire, 2010; Soppe, 2011). The difference is the mixture of materials. Usually micro crystalline silicon and amorphous silicon are used together in the same cell to form so called tandem cells. Therefore amorphous silicon and micro crystalline cells are going to be treated as one technology in this thesis under “thin film silicon solar cells”.

## *Non-Silicon solar cells*

Regarding the high costs of producing Silicon, other cheaper alternatives became interesting replacement options.

**Cadmium Telluride**

Cadmium Telluride (CdTe) thin film solar cells are a good candidate for replacement of Silicon solar cells because their band gap is close to the optimal. The band gap defines how much energy a photon should have in order to create an electron-hole pair. The efficiency of CdTe solar cells can reach 16% under perfect conditions in laboratories and roughly 10% in commercially available products (Griffin, 2010). Some companies have dropped the use of this technology due to the toxicity of Cadmium and the scarcity of Tellurium.

**Copper Indium Diselinide (CIS) solar cells and Copper Indium Gallium diselinide (CIGS)**

The laboratory efficiency of this technology is approximately 20% against 11% for the commercial modules. The drawback of this solar cell technology is that indium is a scarce material that will only satisfy the production of a few Giga Watt of solar cells.

**Organic solar cells**

Two main technologies represent the organic solar cells. These are polymer solar cells and Dye sensitized solar cells. The Dye sensitized solar cells are based on photosynthesis. The organic dye absorbs the sunlight and an electron is released which can be transported into the cell (McConnel, 2002). Polymer solar cells are based on semiconducting polymers (Hoppe, 2008). Benefits of the cells are flexibility and low production costs. The disadvantages at the moment are low efficiencies.

**III-V solar cells**

These are concentrator solar cells using optic systems to bundle the light. The active material used in this technology is usually GaAs (Gallium- Arsenide). These cells reach very high efficiencies but are too expensive to be used for electricity consumption. The technology is therefore used in Aerospace technologies and might be a candidate for large scale energy production in the Desert (Roadmap zon op Nederland, 2011; van Zolingen, 2009). Therefore this technology is not of interest for this thesis.

## *Prices per technology*

Next to the efficiencies, the price is of significant importance. Users of solar cells, like users of any other applications, always have to make a choice between price and efficiency. Table 1.1 gives an overview of the most important cell technologies.

| Technology | Price (2008 $/Wp) | Manufacturing Cost (2008 $/Wp) |
|---|---|---|
| High-efficiency monocrystalline silicon | $3.83 | $2.24 |
| Multicrystalline silicon | $3.43 | $2.12–$3.11[40] |
| Amorphous silicon (a-Si) thin film | $3.00 | $1.80 |
| Copper indium diselenide/copper indium gallium diselenide (CIS/CIGS) thin film | $2.81 | $1.26 |
| Cadmium telluride (CdTe) thin film | $2.51 | $1.25 |

**Table 1.1 Module prices per PV cell technology (Price, 2010)**

There are a couple of important terms that need to be explained considering Photovoltaics and costs. A PV module consists of several PV cells. When these modules are connected to each other one gets a PV array. Finally when all other necessary equipment is connected to the PV array (inverters, cables...), one gets a PV system which is the final completely functional product. A system could also just contain one PV module. When modules are connected in series the output voltage is higher; and when the modules are connected in parallel, the output current increases. The quantity of panels placed in series and in parallel depends on the desired output voltage and current of the system. Figure 1.4 shows how a PV system is obtained from crystalline silicon starting from the raw material.

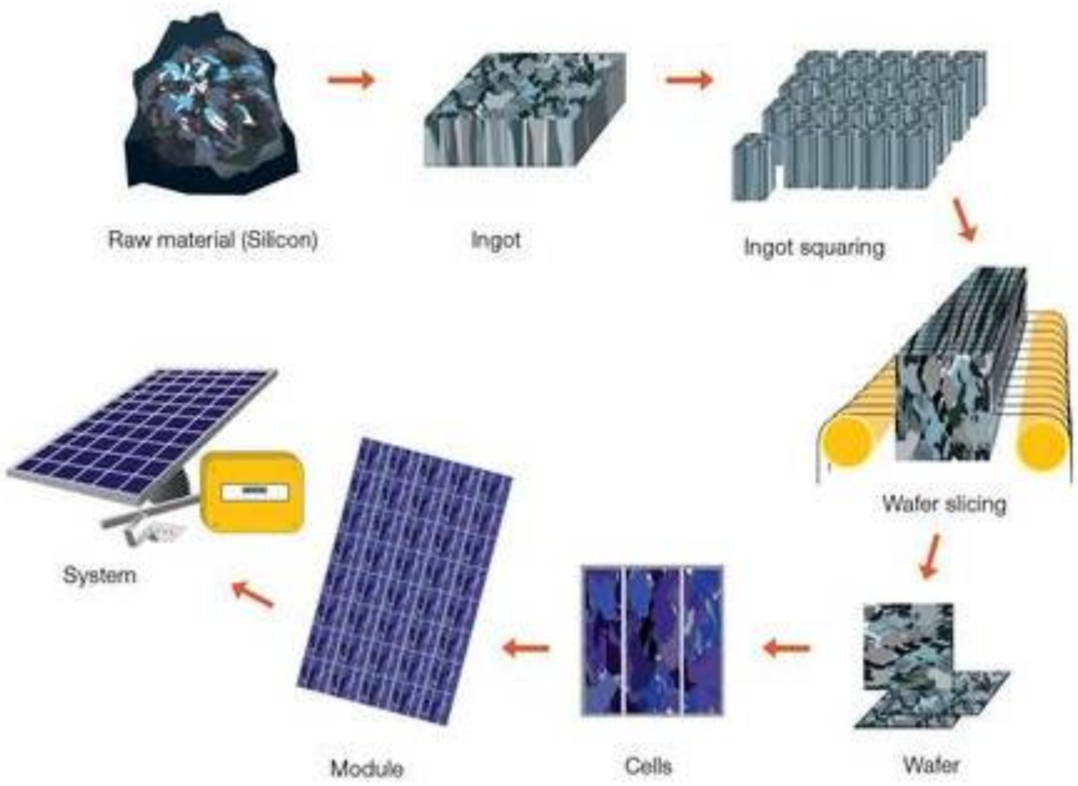


**Figure 1.4: Steps from raw material to PV system for crystalline silicon (EPIA website, 2011)**

Figure 1.5 shows the average price of PV modules between 2002 and 2010. A clear rise in prices can be noticed between 2004 and 2008. This was due to a shortage in silicon feedstock (Price, 2010). The price drop is mainly due to an increase in global production. However, there are more costs involved when actually installing the PV system. In 2007, the average additional costs to install a PV system were 3.8$/Wp. This means that in 2007 the module only represented 56% of the total costs (Price, 2010). An example of costs and gains calculation of PV systems can be found in appendix B.

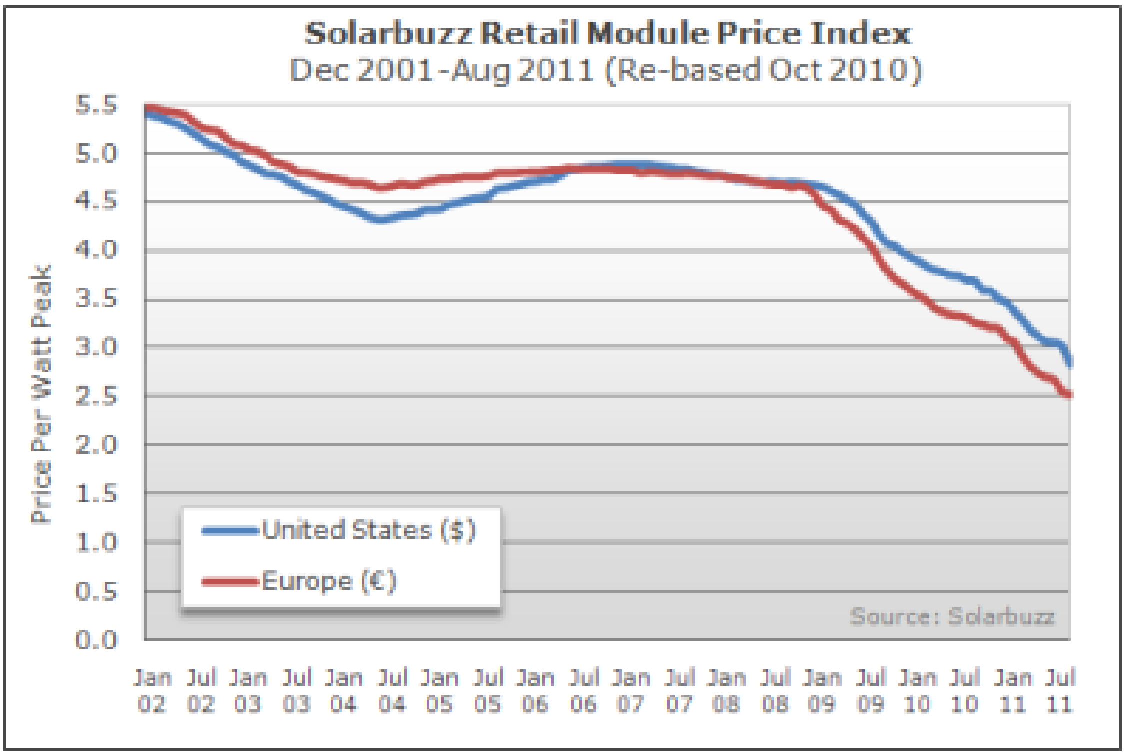


**Figure 1.5: Average module price developments between 2002 and 2011 (Solarbuzz, 2011)**

## 1.5 Methodology

The research is an explorative one. It will study the factors that boost or block the development and diffusion of PV technologies in case of the Netherlands. Therefore the dependent variable of this research is "The development and diffusion of PV technologies in the Netherlands". This dependent variable is influenced by 7 functions defined by the framework of Innovation Systems. Chapter 2 will go more into the details about this framework.

The data that is gathered to find an answer to the research question consists of scientific literature from papers, journals and books on related topics which could be found using internet, the university's library database and the snowball method; company news gathered from annual reports and articles; interviews with people involved with different PV technologies; and results of statistics researches gathered especially from Statistics Netherlands CBS.

The snowball method was mainly used to investigate the history of the technologies in the Netherlands. When more information was needed about a historical fact, the references of a book or article would lead to more detailed information. This method was also handy because many books and articles from the early nineties and eighties are not digitalized. This means that just entering keywords into search engines would never show these books or articles.

The keywords used to browse the internet or the library database were very broad at the beginning. These were keywords like: "Photovoltaics in the Netherlands", "Research, Photovoltaics, Netherlands", "Regulation Photovltaics"... The keywords used were both English and Dutch as the technologies were investigated in case of the Netherlands. These broad keywords would then lead to knowing the main players in the Netherlands regarding PV. Then, their commercial, political and research activities could be investigated.

The people interviewed had to be closely involved in the Photovoltaics industry. The interviews can be found in Appendix C. The interviewees were researchers who are up to date on the newest research topics and collaborations between different parties; sales managers and product managers of companies that are currently involved, or used to be involved, in the Photovoltaics business. These persons have knowledge of the technology and are in direct contact with the market; and promoters of Photovoltaics from governmental or private organizations were also interviewed. The interviews were held to elaborate on ambiguities that still existed after completing the literature research. The interviews were open. This way the needed answers could be gathered in addition to extra useful information that paved the way for new questions and insights.

Names were gathered by first looking for professionals in the direct environment of the TU Delft. Knowing the main research institutes and companies through the literature research, names could be acquired of key actors within these institutes and companies. The names of sales and product managers of other companies were mainly found using LinkedIn. This is a very useful way to find professionals as their CV can be consulted and this way one can assess their experience in the field, and hence whether they could have a lot to tell. Interviewees gathered through LinkedIn were found using keywords like "Sales manager + name of a company". To avoid a bias in the interviews it was avoided to use contacts of the people previously found on LinkedIn. Others were found by directly contacting companies. All this resulted in interviews of approximately 30 minutes and some lasted even longer since most interviewees were very enthusiastic in sharing their knowledge and thoughts.

## 1.6 Managerial implication

The thesis will give companies, and other related organization, insight in the stage of development and diffusion of the available PV technologies in the Netherlands. It will also give an insight in the factors that hinder or boost the development and diffusion of these technologies. This thesis will describe the developments regarding each PV technology since their introduction in the Netherlands. This can be useful for investors who are interested in the Dutch PV industry; and provide them with the needed information on which they can base their investment decisions. Parties involved in a specific PV technology can use the information provided by this thesis to learn about developments concerning the other technologies and how this could affect their business. Dutch policy makers can use this thesis to evaluate the result of former policies and can take the information provided by this thesis into consideration for future policy adaptations.

## 1.7 Scientific relevance

The research proposed will give new insights on the IS of Photovoltaics, different from previous researches done on this subject in the Netherlands. This is done by analyzing the IS of each available PV technology in the Netherlands separately. This will perhaps lead to the discovery of other factors than the ones discovered in previous researches which focused on the PV innovation system as a whole and did not look into the IS of each available technology. Some technologies might be developed and diffused much faster than others and can serve as examples or threats due to competition.

The research will also serve as a comparison between the Netherlands and other pioneers in PV like Japan (Prent, 2008) and Germany (Jacobsson, 2006), for which several researches have been done.

## 1.8 Structure of the thesis

After this introductory chapter, chapter 2 will go more into detail about the global situation of each PV technology describing the main developments, users and producers. Then, chapter 3 will explain the motives for going with Technology Specific Innovation Systems using functional system analysis. In chapter 4 each PV technology will be analyzed using Functions of Innovation Systems (FIS). Chapter 5 will then describe the motors of innovation to analyze the dynamics between the functions. Chapter 6 will then analyze competition between the PV technologies in the Netherlands. Chapter 6 will be followed by the conclusions of the thesis in chapter 7, followed finally by the discussion and recommendations in chapter 8.

# 2. World PV market

This chapter will give an idea about the global situation of the selected PV technologies. This will be done by first mapping out which countries are playing a significant role on the demand side in paragraph 2.1. Then, paragraph 2.2 will present the leading manufacturing countries. Paragraph 2.3 will explain which countries spend most on R&D and how this money is spent. Finally, paragraph 2.4 will go more into detail about the global developments per technology.

## 2.1 Global PV energy production and leading countries

Today PV accounts for about 0.1% of the total electricity generated worldwide (International energy agency (IEA), 2010). Crystalline silicon modules represent 85-90% of the global market, whereas modules based on thin film solar cells represent 10% to 15% of the global market. Other emerging technologies like organic solar cells are still subject of research and are about to enter the market via niche applications (IEA, 2010).

Even though the market represents only 0.1% of the global electricity production, the growth of the PV market shows an average of 60% per year during the period 2004-2009 (REN21, 2010). This is depicted in Figure 2.1, which represents the existing world capacity of Photovoltaics.

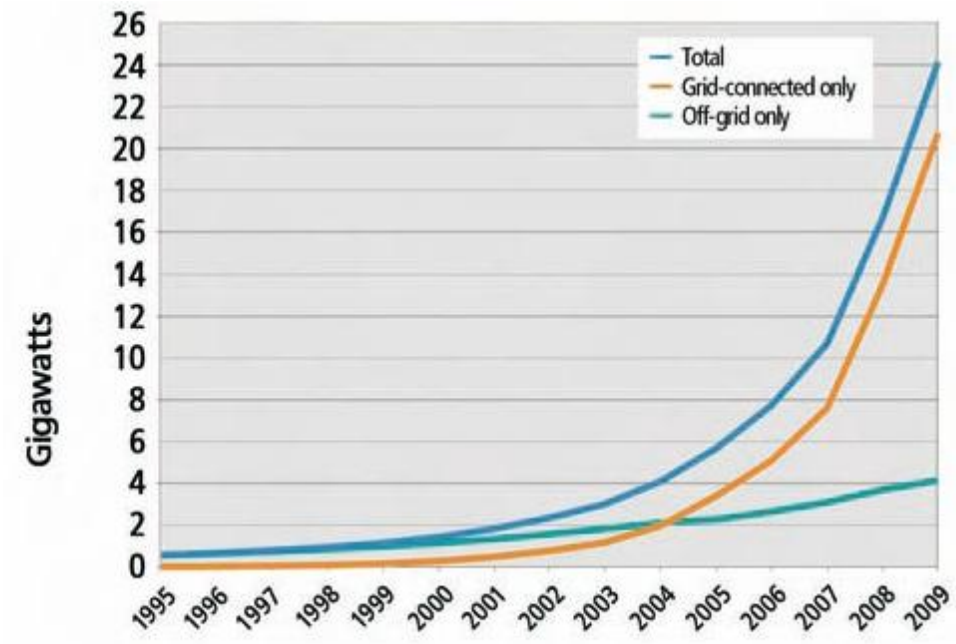


**Figure 2.1: Existing world capacity of PV between 1995 and 2009 (REN21, 2010)**

Germany, Spain, Japan and the US represent together more than 80% of the global installed PV capacity producing respectively 9.8, 3.4, 2.6 and 1.2 GigaWatt. Figure 2.2 shows the rapid change in PV- energy production shares between the years 2000 and 2008.

With their 9.8 GigaWatt, Germany reached a world capacity share of 47% in 2009 (REN21, 2010). This was thanks to its subsidies and feed-in tariffs (Chew, 2010). Spain, with a share of 16% in 2009 increased its capacity by 70 MW, which is a lower increase than the year 2008 due to lower subsidies as the national target was already reached (REN21, 2010). Japan, occupying 13% of the global PV capacity, increased its capacity that year with 485 MW after reinstating residential rebates and introducing a buy-back program for residential rooftop systems (REN21, 2010). The US added 470 MW in 2009, taking 6% of the global PV capacity. Half of the capacity in the US was produced in California followed by New Jersey. The increase in the US was a result of tax and cost reductions (REN21, 2010).

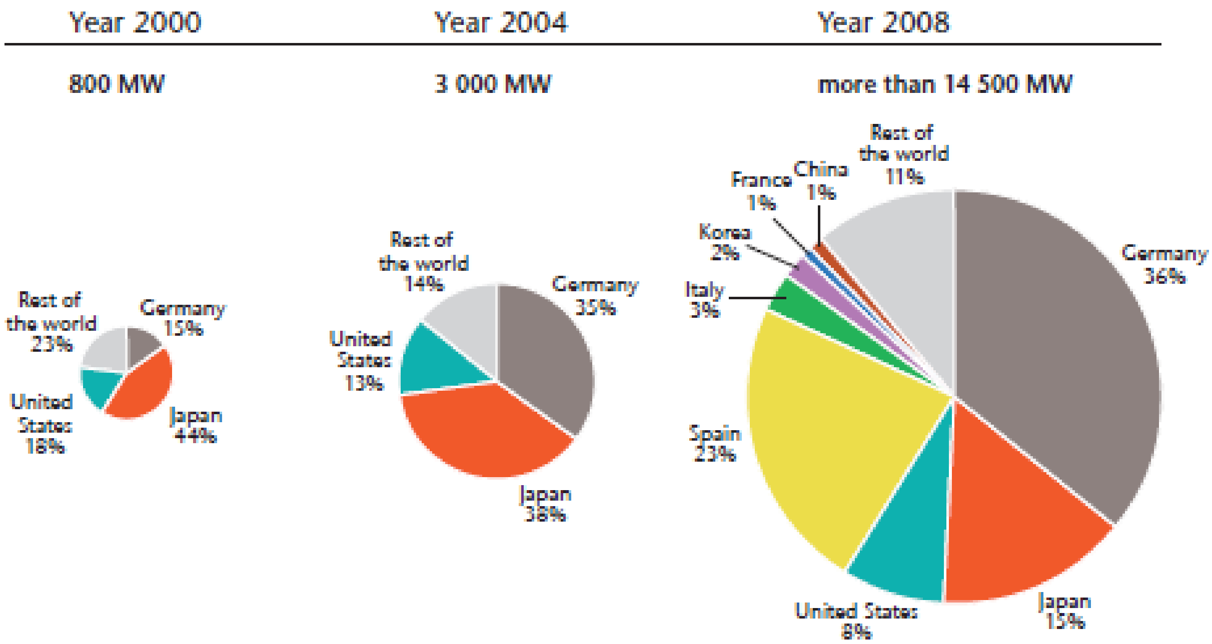


**Figure 2.2: Distribution of the PV capacity worldwide at different periods (IEA, 2010)**

## 2.2 PV industry development and leading companies

The prices of PV modules showed promising declines dropping from $3.50 per watt to even $2.00 in some cases in 2009 (REN21, 2010). This made many buyers to delay their order waiting for even lower prices. Many companies had difficulties coping with this softening in demand. Many firms therefore focused on increasing their efficiency, reducing costs and increasing capacity utilization at their factories to profit from economies of scale. Many companies turned to project development besides manufacturing to increase the future demand for their modules.

The number of companies producing Thin film solar cells dropped from approximately 150 companies in 2008 to about 70 in 2009 (REN21, 2010). This was because Thin-film solar cells were losing their big cost advantage compared to crystalline PV modules.

Nearly half of the PV module producers (49%) are situated in China and Taiwan. European companies had 18% of the market in 2009. Japanese companies represented 14%, followed by the US with 6% market share. The top 15 of PV module producers is depicted in Figure 2.3.

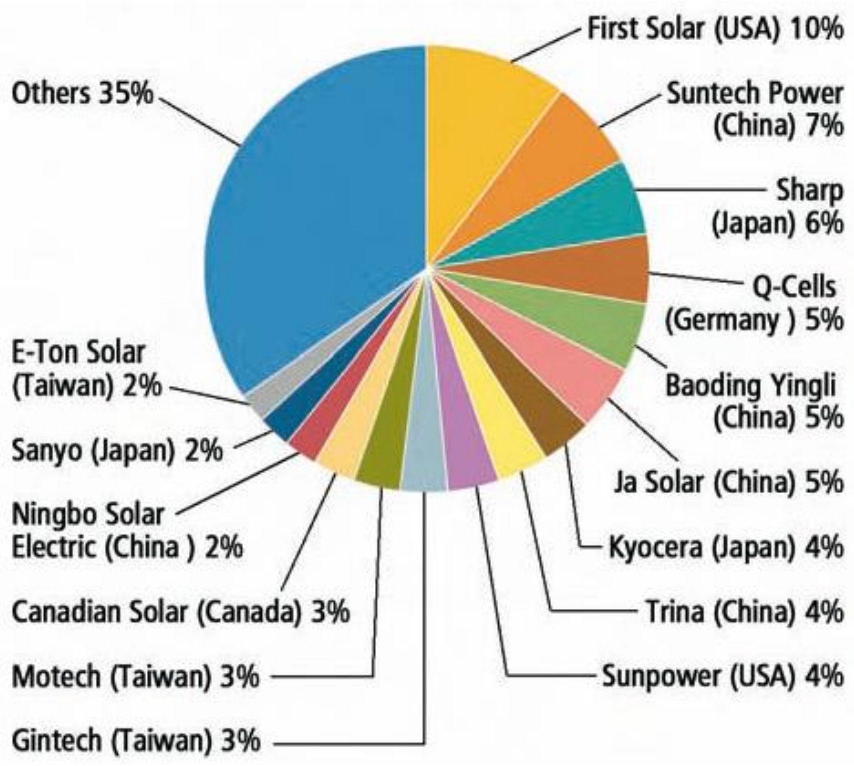


**Figure 2.3: Top 15 PV manufacturers in 2009 (IEA, 2010)**

## 2.3 Global R&D spending

The public R&D expenditures in the key countries have doubled during the period 2000-2007 from about $250 million to $500 million. This ranges from research on raw material to the production of modules (IEA, 2010). Figure 2.4 shows how much each of the key countries spent on R&D between 1998 and 2007.

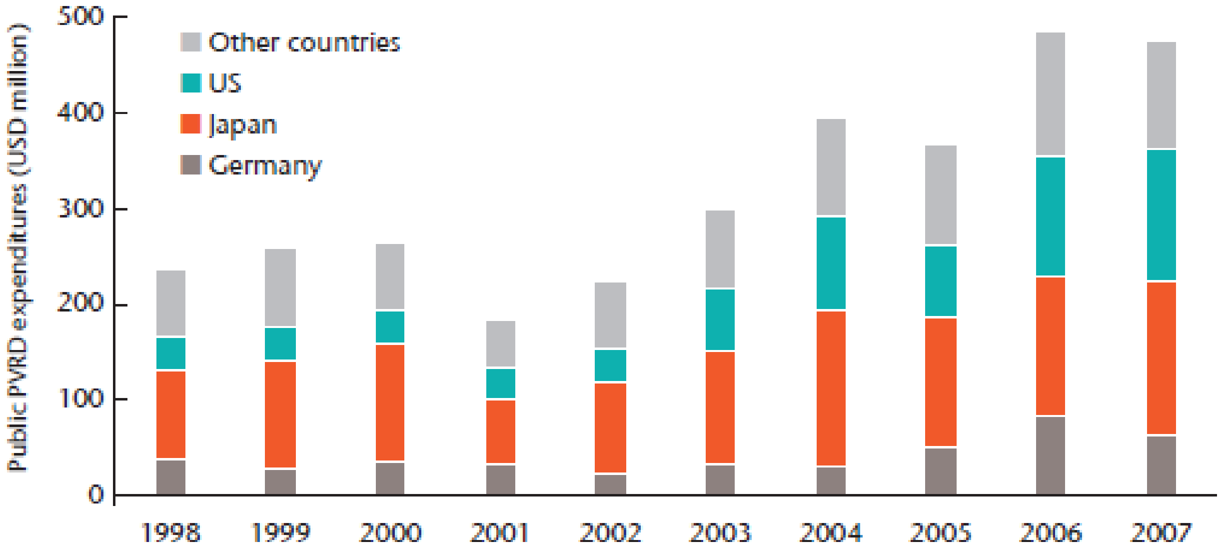


**Figure 2.4: public R&D expenditures in key countries (IEA, 2010)**

A large number of initiatives have taken place around the world to promote R&D on Photovoltaics (IEA, 2010). A lot of attention is given to roadmaps to assess the best R&D options (Japan). Scenario planning in the European Union is aiming at exploring different scenarios for PV and how to cope with them to reach a rapid adaptation of PV.

75% of the global R&D spending has been dedicated to the solar cells and modules. The other 25% has been assigned to all other related research on complementary technologies and production processes (IEA, 2010). Research at the European PV Technology Platform and the Solar America Initiative (SAI) is spending money on the R&D of all kinds of technologies along the value chain of PV.

## 2.4 Developments per technology

Figure 2.5 shows the market share developments of the different PV technologies during the last decades. Crystalline silicon solar cells have always been the market leader with market shares higher than 80%. Until 2005, amorphous silicon was the leading thin film technology (EPIA, 2011). Amorphous silicon is however also used in consumer electronics which means that crystalline silicon had a bigger share than estimated in Figure 3.5 when it comes to panels.

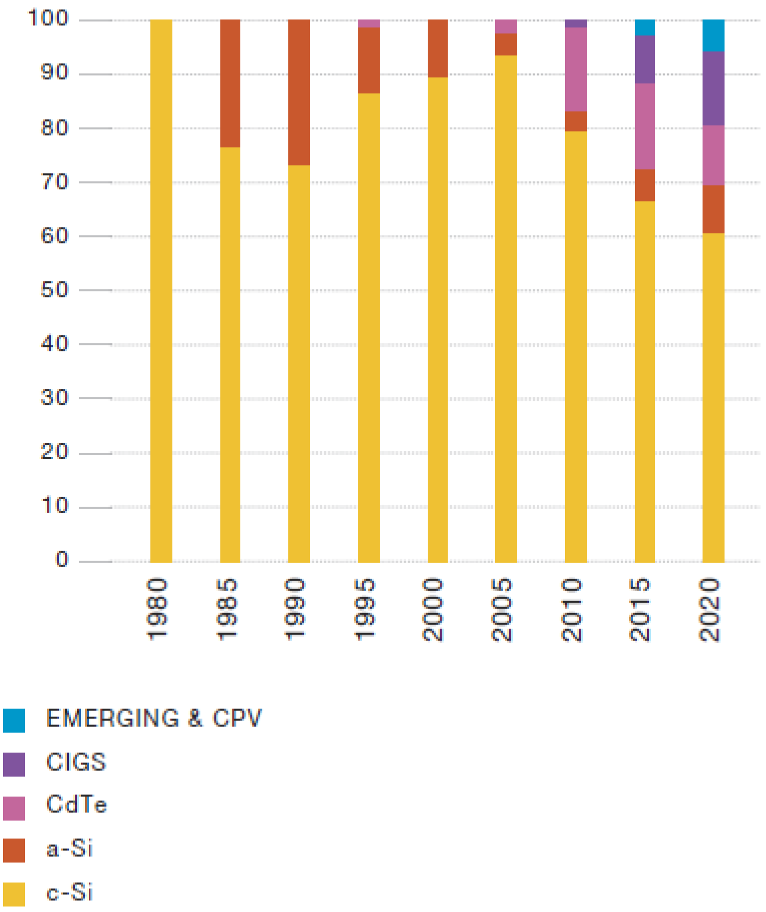


**Figure 2.5: Market share developments of PV technologies (EPIA, 2011)**

**Crystalline silicon solar cells**

Crystalline silicon solar cells have the highest market share by far up until now. In 2009 mono-crystalline silicon solar cells had about 37% of the solar cell market and poly-crystalline represented 45% of the market. Ribbon silicon solar cells which are actually multi-crystalline silicon cells had a market share of 2% in 2009.

The production of silicon has for a long time been dependent only on the micro-electronics industry. Silicon is abundant because it is extracted from sand. Nevertheless, when around 2008 the demand from the solar industry surpassed the demand from the micro-electronics industry, the silicon producers could not apply to the demand. The result was that the price of silicon increased significantly leading to higher PV panel prices (Wolden, 2011). Due to a rise in number of silicon producers, scarcity is not an issue anymore for silicon (Wolden, 2011; Zeman, 2011; Weeber, 2011; Soppe, 2011). The silicon produced for the solar cell industry is called solar grade silicon and does not need to be as pure as electronic grade silicon used in the micro-electronics industry (Wolden, 2011).

Crystalline silicon wafer production technologies are highly standardized (Weeber, 2011). Adding that up to the abundance of silicon and the relatively high efficiencies results in a very competitive technology that is difficult to compete with. This shows in division of market share among the solar cell technologies that is depicted in Figure 2.5

**Thin Film silicon solar cells (TF-Si)**

This technology was demonstrated around 1969 and has the longest history among the thin-film technologies. There are several different TF-Si technologies like single junction amorphous silicon (a-Si), double junction a-Si, germanium-doped amorphous silicon, micro-crystalline silicon and many more (Schmidke, 2010).

Early producers of this technology were Sharp, Kaneka and United Solar Ovonic. The number of companies has risen rapidly since 2005. The most important producers are listed in Table 2.1. In 2009, the production capacity among 80 firms worldwide as about 1000 MW whereas the total installed capacity reached 300 MW. This was mainly due to the high material and capital costs, low module efficiencies and limited market for the modules (Schmidtke, 2010). This led to the insolvency of some companies while others try to improve the efficiency of their modules and try to reduce costs.

Amorphous silicon solar cells have for a great part been used in indoor consumer electronics, at least until 2003 (Goetzberger, 2003).

| Company | Active layer | Module type | Efficiency (%) |
|---|---|---|---|
| Bosch Solar Thin Film | a-Si/μc-Si[a] | glass/glass | 7.0% - 8.0% |
| Kaneka | a-Si | glass/glass | 6.3% |
| | a-Si/μc-Si | glass/glass | 9.0% |
| Masdar PV | a-Si[b] | glass/glass | 6.0%-7.0% |
| Sharp | a-Si/μc-Si | glass/polymer backskin | 8.1%-9.9% |
| Schott Solar | a-Si[a] | glass/glass | 6.6%-7.1% |
| Uni-Solar | a-Si/a-SiGe/a-SiGe | Flexible, SS foil substrate | 6.6%-8.2% |
| | a-Si/nc-Si/nc-Si | Flexible, SS foil substrate | 12.5%[c] |

**Table 2.1: TF-Si module producers (Schmidtke, 2010)**

### Cadmium telluride (CdTe) thin-film modules

This technology now has the most success among the available thin-film technologies. In 2009 the sales surpassed 1000 MW. The costs of CdTe modules range between $2.3 and $2.5 per Watt peak (Nielsen, 2010). The market share of CdTe panels has risen from 2% in 2005 to 13% in 2010. The American company First Solar is the leading company regarding this technology having a production capacity of 1416 MW. The production costs of their panels reached 0.76 $/Wp in 2010 (Schmidtke, 2010).The technology has the lowest production costs on the market (schmidtke, 2010). These costs are expected to even reach $0.52/Wp in 2014. About 4 companies worldwide manufacture CdTe solar cells (EPIA, 2011).

### Copper indium (gallium) diselenide (CIS/CIGS) thin-film modules

The first commercial products of this technology have been introduced in 2006 by Würth Solar, in Germany (Wirtz, 2010). The global actual production levels are far less than announced at first. The company with the highest estimated production capacity is an American company called Nanosolar with an estimated capacity of 640 MW (Schmidtke, 2010). The production costs of this technology are about 2 dollars per Watt peak (Nielsen, 2010).

Indium which is used in these cells is available in limited quantities (EPIA, 2011; Wolden, 2011). Indium is also used in LCD displays which accounts for 85% of the demand. Shortages can occur (Soppe, 2011; Epia, 2011) which drive the price up and can make CIS/CIGS lose their relative cost advantage that they have at the moment compared to crystalline silicon cells.

Current efficiencies of CIS/CIGS cells have reached 20.3% in laboratories and the highest commercial modules have efficiencies of 12.1%. There are 30 companies producing CIS/CIGS worldwide. The production is quite complicated compared to other thin film technologies and less standardized. This is one of the main causes for CIS/CIGS to have higher process costs than other thin film technologies (EPIA, 2011).

### Organic photovoltaics

Commercial models of this technology reach around 2% of efficiency. Therefore the commercial uptake is still limited (Schmidtke, 2010). Nevertheless, many companies are developing organic PV technologies like Sharp, Sony, Mitsubishi Chemical and others. There is no established market for organic PV systems (Nielsen, 2010). The type of companies involved in this technology are companies financed by venture capitalists and small companies addressing niche markets. The large companies have large patent portfolios hoping their technologies will catch on and that they will have no interference from competing companies.

The only company with commercially available solar cells is Konarka Technologies. The price of the cells is about $11/Wp, with a 3% efficiency making it very difficult for the moment for this technology to compete with other existing technologies (Nielsen, 2010).

The expectations are that Organic Photovoltaics will start to be implemented this year in small consumer applications like small toys and smartcards. The implementation in medium scale stand-alone systems is expected to be around the year 2015 (Nielsen, 2010). These expectations are based on the current status, the history and number of patents regarding this technology.

# 3. Theoretical framework

This chapter is going to describe the framework that is going to be used to analyze the factors that boost or hamper the development and diffusion of PV technologies in the Netherlands. Paragraph 3.1 will explain the selection criteria for theoretical models. Paragraph 3.2 will explain the theoretical models that analyze innovation and technological transitions and fulfill some of the selection criteria. Paragraph 3.3 will then evaluate which theoretical model fulfills most of the criteria and will be used as theoretical framework for this thesis. The indicators used for the chosen framework were changed slightly in order to fit within the time scope of this thesis. These indicators are presented in paragraph 3.4.

## 3.1 Selection criteria

This thesis is going to investigate the factors that boost or hamper the development and diffusion of PV technologies in the Netherlands. The previous paragraph showed that PV represents only 0.1% of the global electricity production. Meanwhile, between 2004 and 2009, the PV market grew about 60% per year.  This means that PV technologies are emerging technologies. The increasing R&D spending worldwide shows that there are still a lot of developments ongoing and possible with the different PV technologies. The number of firms is changing rapidly (upwards and downwards), and sometimes expectations of some technologies turn out to be too ambitious. This shows that the actors involved in the PV technologies are operating in a very dynamic environment and react rapidly on each other's actions. The fact that the installed capacity is still 0.1% worldwide and 0.0003% in the Netherlands, years after invention of the first cells, shows that there are difficulties in overthrowing the incumbent energy production technologies which are mainly based on fossil fuels. Besides, the success of the technologies is dependent on factors that lay outside of the reach of the actors involved. These are factors like availability of natural resources and environmental problems.

PV technologies and their environments have certain characteristics which will determine the selection criteria for the models eligible to analyze the factors that boost or hamper the development and diffusion of these technologies in the Netherlands. These characteristics are described in Figure 3.1. Figure 3.1 also shows the selection criteria that result out of the numerous characteristics of the PV technologies and the environment in which they operate.

The main selection criteria that result out of the characteristics of the PV technologies are:

- That the model used to answer the research question has to focus on a specific technology, in this case each of the PV technologies.

- Diffusion of the technology is important, but also research and development of the technologies plays a central role. This is because there is still a lot of research and developments going on.

- As there are many actors involved, the model should be able to analyze multi actor environments.

- The actors react rapidly on each other's actions. Therefore, the feedback between them should be analyzed (dynamic analysis).

- The analysis should be done on a large time span. This is because many developments took place over time. Knowing what happened in the past explains certain actions of the involved actors.

- There are also decisive factors like availability of resources and environmental problems on which the actors have little influence. Actors within a certain country are also dependent on international (technological) developments.  Therefore the model has to include these kinds of factors.

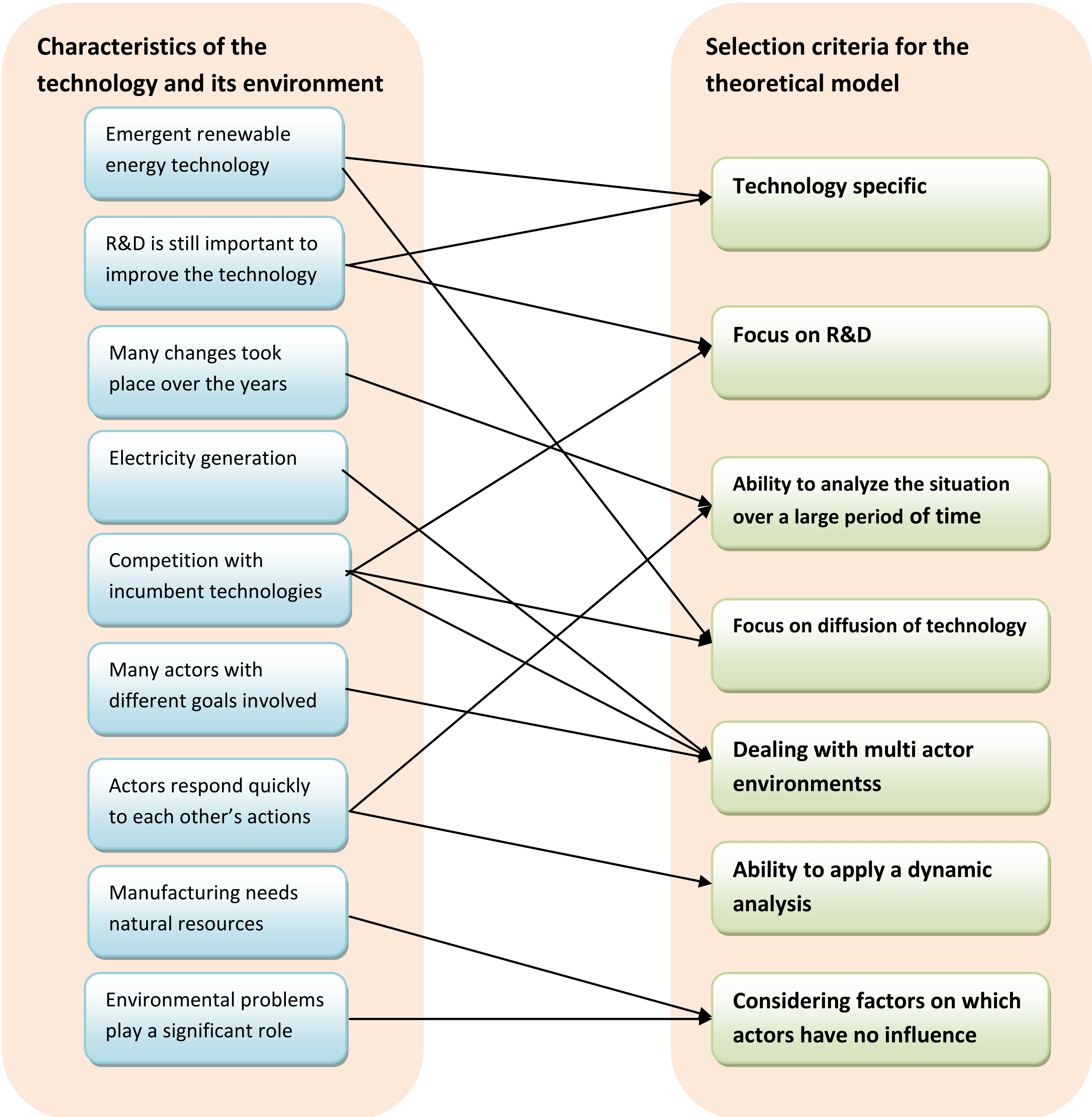


**Figure 3.1: Selection criteria for the theoretical model to be applied (right) based on characteristics of the PV technologies (left)**

## 3.2 Approaches to analyze innovation and technological transitions

### *Porter's Diamond framework*

Porter proposed in his book "The competitive advantage of Nations" (1990) a framework to answer the following question "Why do firms based in particular nations achieve international success in certain segments and industries?" (van den Bosch, 1992). To answer this question, the framework proposed by Porter contains four interrelated elements. These elements are: Factor conditions; demand conditions; related and supporting industries; and the firm's strategy, structure and rivalry. Factor conditions consist of the available inputs of production (human resources, capital resources, information infrastructure...) (Porter, 2002). The Demand condition is explained as the nature of home demand for the industry's product or service. The third element of the framework "Related and supporting industries" deals with the existence of a national environment of internationally-competitive related and supporting industries (van den Bosch, 1992). The fourth element (The firm's strategy, structure and rivalry) is dependent on the presence of local policies and incentives, such as intellectual property protection, that encourage investments and sustained upgrading. The presence of local competitors is also a key point of this fourth element.

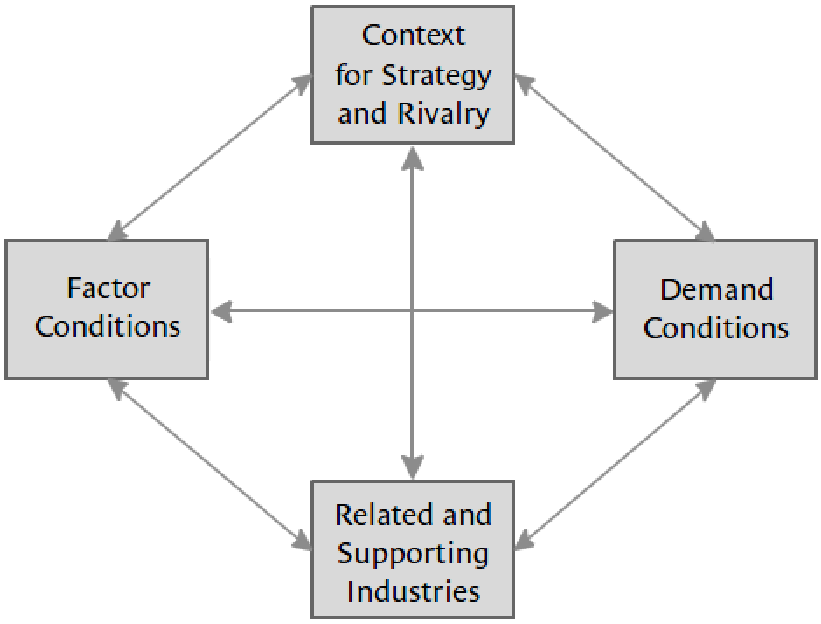


**Figure 3.2: The elements of Porter's Diamond framework (Porter,2002)**

Porter's Diamond framework focuses more on relations within the national border of a nation and neglects factors from outside the country. Critics of Porter's Diamond framework argued that this framework lacks attention to cultural influences (van den Bosch, 1992). Others argue that non-market interactions are neglected and that the analysis is static (Carlsson, 2002). A system is called "Dynamic" when there is Feedback or interaction between the components (Carlsson, 2002). Without feedback, a system is considered static.

### *The multilevel perspective*

Technological transitions are dependent on the alignment of three levels: the Macro, Meso and Micro level (Figure 3.3). Each of these levels has a different level of "vulnerability" to outer factors or resistivity to change. The most difficult level to change, and the one that is least affected by the other levels, is the Macro level. This level is also called the Socio-Technical Landscape. This landscape contains a heterogeneous set of factors like oil prices, wars, political coalitions, environmental problems etc (Geels, 2002). In other words, the Landscape is defined by factors that are not necessarily technological and are not easily affected by new technologies.

The Meso level represents the socio-technical regime. A socio-technical regime is a set of semi-coherent rules carried out by different social groups. These rules are meant to maintain the stability of the linkages between heterogeneous elements forming a socio-technical configuration (Geels, 2002). The Meso level is a stable highly interrelated structure characterized by established products, technologies, stocks of knowledge, user practices; and norms and regulations (Markard, 2008). The stability of a regime is of a dynamic kind, which means that there is possibility for innovation but more in an incremental way.

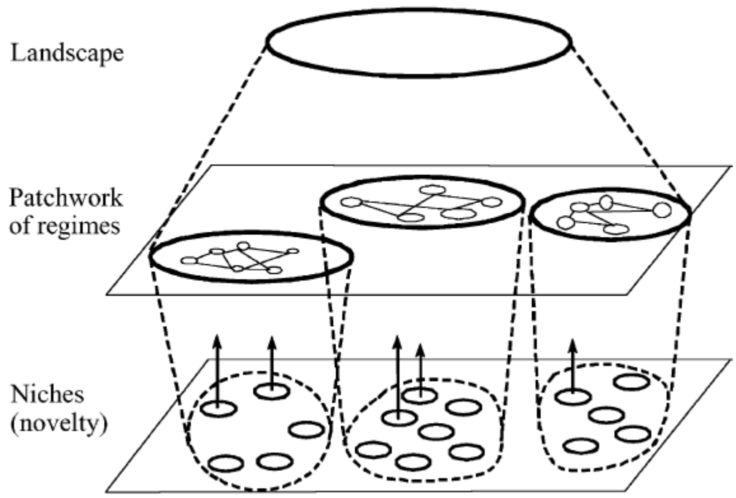


**Figure 3.3: The three levels of the multi-level perspective (Geels, 2002)**

Radical innovations are created at the Micro level within the "niches" that are forming this level. These niches are incubation rooms for these radical innovations to protect them from the usual selection procedures of regimes. Niches are locations for learning processes. Learning by doing, learning by using and learning by interacting. These are all kinds of learning processes preparing the innovation to be accepted within a regime.

The success of a new technology is not only dependent on its success within a niche but also, for a great part, on changes within a regime. This creates a window of opportunity for the technology to establish itself as part of the new regime. Changes in the regime can be triggered by changes in the Landscape, or Macro level, which may put pressure on the regime and create openings for new technologies (Geels, 2002).

### *Large technological systems*

Large technological systems (LTS) contain messy, complex problem solving components (Hughes, 1987). The technological system can be shaped by society or the system itself can shape society. The components are physical artifacts; legislative artifacts like rules and regulations; organizations; scientific components like articles and teaching; and natural resources. These components interact to reach the goals of the system. Everything external to the system is called the environment. The framework is used to analyze the creation and growth of big systems like those of electric supply systems (Hughes, 1983).

The expansion of a LTS happens in phases: Invention & development, transfer, growth and momentum (Hughes, 1983). During the first stage, the most important actors are inventor-entrepreneurs who invent the system but also stay involved in the development until and after the system is ready to be used. Engineers and financiers also play significant roles in this stage. The second phase implies the transfer of technology from one region of society to another. When a system solves problems caused by weak spots or "reverse salients" and there is enough demand for the product, the system enters the growth phase. As a system grows, it acquires momentum. A system with momentum has mass (physical artifacts, actors), velocity (growth rate) and a direction which consists of the goals of the system.

### *National Systems of Innovation*

The first persons to have used the term "National System of Innovation" (NSI) were B. Lundvall and C. Freeman (carlsson 2002; Freeman 1995). However the idea goes back to the conception of "The National System of Politcal Economy" by Friedrich List in 1841. Freeman defined NSI as "The network of institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies" (Edquist, 2004).

The National Innovation System approach is broad, such that it does not only include industries and firms, but it also includes other important actors playing significant roles in science, technology and policy. All these actors are analyzed within national borders. These actors can be national universities, research institutes and government agencies. The main focus though is mostly on the role of non-firm organizations and institutions.

The concept of National Systems of Innovations (NSI) was used by Freeman (1995) to explain the technological advance of Germany, the US and Japan compared to other nations. He argued that "institutional differences in the mode of importing, improving, developing and diffusing new technologies, products and processes played a major role in the sharply contrasting growth rates in the 1980s". Institutions play a significant role in these countries in promoting scientific research and the adaptation of new and better technologies. Also the linkages between the key actors in innovation, like universities and companies play a major role. The government of the USSR, for example, made significant investments in the defense and space industry, whereas Japan focused on the upcoming technologies like electronics and communication. The USSR had many labs and R&D facilities; however these did not have interconnected relationships. Japan, on the other hand encourages strong cooperation between R&D facilities and the corporate world. The result was that around the seventies, Japan was very competitive in international market and the USSR was almost non-existent on the international market except for the military industry.

Promoters of the NSI framework believe that the development and diffusion of innovations within a country is mainly dependent on factors within the borders of the country (institutions, regulations, entrepreneurial activity, R&D expenses…). They argue that globalization can have its influences but without a strong National System of Innovation, innovations cannot be developed and diffused.

### *Sectoral Innovation Systems*

A sector is "a set of activities that are unified by some linked product group for a given or emerging demand and which share some common knowledge" (Malerba, 2004a).

A Sectoral Innovation System is a set of new and established products for specific uses and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products (Malerba, 2004b). The basic elements of Sectoral Innovation System are:

- Products
- Agents: these are organizations and individuals (firms, universities, government agencies, producers, suppliers…). They are characterized by specific learning processes, organizational structures and behaviors. Their interactions are shaped by institutions (rules and regulations) (Malerba, 2002).
- Knowledge and learning processes: Knowledge plays a central role in innovation and production.
- Basic technologies, inputs, demand, and related links and complementarities: These include interdependencies among vertically or horizontally related sectors, the convergence of separated products or the emergence of new demand. These interdependencies define the boundaries of the system. They may be at the input, technology or the demand level and concern innovation, production and sale.
- Mechanisms of interaction within and outside firms: Agents are examined on their market and non-market interactions.
- Processes of competition and selection: New knowledge can lead to the creation of new sectors and agents (Malerba, 2002). The entrance of new agents, like firms, brings new knowledge and processes leading to more innovations and products. These processes are important for the dynamics of the Innovation System. The selection process limits the amount of agents and sectors and changes their behavior.
- Institutions: like standards, regulations and labor markets.

The sectoral approach differs from the National System of Innovation approach in the fact that Sectoral Innovation System are not bounded by national boundaries of a country it can have local, national and global dimensions (Malerba, 2004). On the other hand, National Systems of Innovation greatly depends on Sectoral Systems of Innovation. A National Innovation System can be the result of the composition of different sectors (Malerba, 2004). This means that the national economy can grow due to specific sectors. On the other hand, Sectoral Systems of Innovation are dependent on the National System of Innovation of a nation. This can be due to national or regional institutions affecting the dynamics within a sector.

## *Technology Specific Innovation Systems (TSIS)*

### *Definition of TSIS*

Hekkert (2007) renamed the concept of "Technological Systems" created by Carlsson and Stankiewicz (1991) to "Technology Specific Innovation Systems". This was because a lot of researchers confused it with "Large technological Systems" by Hughes (1987). Bergek et al. (2006) used the name "Technological Innovation System" for the same framework (Bergek, 2006).

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). Technological systems are defined in terms of networks consisting of knowledge and competence flows rather than flows of ordinary goods and services. With the presence of entrepreneurs and a sufficient critical mass, these networks can be transformed into development blocks. The development blocks are synergetic clusters of interdependent sectors, technologies and firms between which exist "untraded interdependencies". This means, their relationships go beyond a simple exchange of commodities.

Technology Specific Innovation Systems cannot be limited to national or sectoral boundaries (Hekkert, 2007). Various companies and research facilities in the world may work to improve the same technology. These facilities also work together and their results are shared among each other. As a result, the success of a technology does not only depend on national or regional factors.

The Technology Specific Innovation System therefore encompasses the National Innovation System and Sectoral Innovation System in addition to factors that lay outside of the boundaries of the last two approaches. Figure 3.4 illustrates that a TSIS can be regarded as the link between several National and Sectoral Innovation Systems.

Technological change is not determined by a simple competition between technologies but rather by the competition between several existing innovation systems (Hekkert, 2007). Carlsson & Stankiewicz, 1991, also presented technology specific innovation systems as an attractive framework to analyze the competition between emerging technologies and incumbent technologies. This is mainly due to the technology-specific features of the approach.

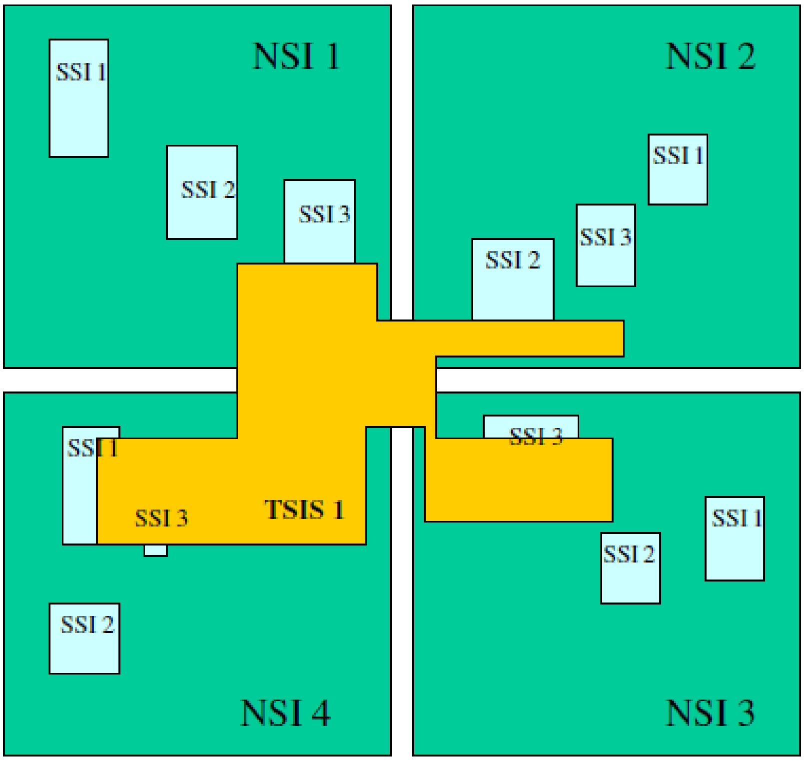


**Figure 3.4: TSIS in comparison to National and Regional Innovation Systems (Hekkert, 2007)**

### *Functions of Innovation Systems (FIS)*

It is difficult to assess whether a particular structure of an innovation system is good or bad (Bergek, 2008). Just listing the components of the system and the relationship between them is not enough to make conclusion on the wellbeing of a system. It is important to analyze what influence each actor has on the innovation process by analyzing what these components actually do and what the consequences were to the system. Therefore, so called "functions of innovation systems" were introduced, outlining seven key processes which have a direct impact on the development, diffusion and use of new technologies (Bergek, 2008a; Bergek, 2008b; Hekkert, 2007). These functions encompass the theories of previous literature on innovation and technological transition like Porter's Diamond model, different innovation system frameworks and the theories on socio-technical regimes (Bergek, 2008b). According to Bergek (2008b), some of the researches focused too much on specific elements of the system, neglecting other important ones. In this paragraph, the functions of innovation systems are going to be discussed in more detail. The focus of this thesis is going to be more on the qualitative indicators of these functions. This is due to the time scope of the research. The indicators are based on (Bergek, 2008b), (Kamp, 2009), (Hekkert, 2007) and (Hekkert, 2009).

**Function 1: Entrepreneurial activities**

Entrepreneurs are key players when it comes to the well functioning of an innovation system. They are important because they take risks through which behaviors of consumers, governments, competitors and suppliers can be assessed. Their role is to create business opportunities using the knowledge, networks and markets they have at their disposal. These entrepreneurs can be new entrants or already existing companies looking to make advantage of new developments. The presence of active entrepreneurs can give a first good indication about the functioning of an innovation system. A poor number of entrepreneurs may indicate a deficiency in one of the other functions of an Innovation System. Moreover, the experience entrepreneurs get from being active within certain IS can induce learning by doing. Knowledge becomes valuable when it is transformed into marketable product.

Entrepreneurial activity can be measured looking at the following aspects:

- Type of entrepreneurs active in the technology field.
- Increase in Entrepreneurs
- Complementary technologies employed.
- Recent and future (announced) activities

**Function 2: Knowledge development**

Knowledge is the most important resource in today's economy; and the most important process to gather this knowledge is learning (Bergek, 2006). Learning can be done by doing, like entrepreneurial activities, or by searching. Therefore R&D and knowledge development are key aspects in an innovation system. Knowledge development can be assessed by for example:

- Defining the type of organizations that perform the research.
- Defining the type of research done.

**Function 3: Knowledge diffusion through networks**

Networks are important for the exchange of information. Learning by interacting is the result of information exchange between different important actors in an innovation system. Entrepreneurs, for example, need to be up to date on the newest developments regarding their products by consulting their network of suppliers and scientists. They also need their networks to get information on or influence certain rules and regulations that affect their business.

This function can be analyzed by assessing:

- The number of workshops and conferences devoted to a certain technology
- The collaboration between organizations on R&D
- Formalized exchange methods

**Function 4: Guidance of the search**

This function refers to the activities within an innovation system that positively affect the visibility and clarity of specific wants among the technology users. Changing preferences among society, when visible, can induce changes in the priority of R&D research or technological change (Hekkert, 2007). For example when long term goals are defined by the government, parties involved can use these goals as a "guarantee" that everything they do in favor of these goals will be appreciated and stimulated.

Changing preferences can be triggered by: change in prices, changes in the “landscape” (see multilevel model), or the development of complementary resources (Bergek, 2008).

Again, networks play an important role for the sharing of information between different actors within a system to get an image on what their preferences are and to react on them.

This function can be measured by assessing:

- Targets set by the government and the industry and of what type they are (focused on research or on the market)
- Trends of customers’ interests
- Technological expectations
- Expectations on the further development and diffusion of the technology

**Function 5: Market formation**

It is difficult for some technologies to compete with the already existing technologies. Therefore it is important that these technologies have some kind of protection. This can be realized through creating niche markets. In this case the technology can be used for a specific purpose, which is not its only purpose, until it proves its efficiency and gets adapted in other fields. Other possibilities are certain rules and regulations that make the technology an attractive option at the expense of the already existing technologies.

The market formation function can therefore be analyzed by assessing:

- The market size
- The niche markets that have been introduced.
- Financial market incentives.
- Who the users are and what their purchasing processes look like

**Function 6: Resources mobilization**

Financial and human capital is necessary for all activities within an innovation system. Therefore allocation of sufficient resources is crucial. An example can be: funds to make R&D programs possible or to allow the testing of a technology within a niche market.

This function can be measured by assessing:

- Availability of venture capital.
- Availability of (research) employees.
- Availability of specialized education programs.
- Availability of raw material.
- The change in volume of investments or venture capital.
- The change in volume of human capital (number of university degrees in a certain field).

**Function 7: Creation of legitimacy/counteract resistance to change**

It is important for the diffusion of a technology that there is an adequate group of supporters. This group can function as a catalyst. They bring the technology to the attention of the important actors of an Innovation System and they make enough funding available in order to do sufficient research to improve the technology and bring it to the market.

Legitimacy is the social acceptance of a certain technology or change. It is not given, but is formed through actions of advocacy organizations and individuals (Bergek, 2008). This process is difficult due to the existence of adversaries defending other Technology Specific Innovation Systems.

To assess this function one needs to:

- Analyze the alignment between the TSIS and the current legislation and values.
- Assess what influences the legitimacy.
- Assess the existence of advocacy coalitions and their activities.
- Assess the results of the advocacy coalition’s activities

### *Virtuous and vicious cycles*

The function of innovation systems are interrelated and influence each other (Hekkert, 2007). When the functions influence each other positively, there is a so called virtuous cycle. These virtuous cycles are necessary to for structural change and systemic innovation (Hekkert, 2007). To illustrate, entrepreneurial activities [F1] can lead to increasing knowledge [F2] which in turn leads to more experimentation [F1] and an increase in lobbying activities [F7] which changes the preferences among people and government [F4].

Vicious cycles, on the hand, are created when a negative change in one function negatively influences other functions, which in turn hinders the progress in other functions. This hinders the development and diffusion of a technology.

Developments within a TSIS often start with a certain number of functions that trigger the other function of a TSIS. These functions are called motors of change (Hekkert, 2007).

Suurs and Hekkert (2010) identified 5 motors of innovation regarding sustainable innovations. They called these motors “motors of sustainable innovation”. These motors are related. In fact, each motor can evolve into another motor when certain conditions are fulfilled. The rest of this paragraph will devoted to the elaboration on these motors of sustainable innovation.

***The science and technology push (STP) motor***

The STP motor is dominated by the functions Knowledge development [F2], Knowledge diffusion [F3], Guidance of the search [F4] and Resource mobilization [F6]. Entrepreneurial activities are weak or even absent. The support of advocacy coalitions [F7] can also play a role in some cases. Virtuous cycles usually start at Guidance of the search [F4] leading to resource mobilization, which in turn leads to Knowledge development and diffusion [F2, F3]. This again leads to more Guidance of the search [F4]. Another cycle which can be part of the STP motor starts with guidance of the search [F4], which leads to resource mobilization [F6], which in turn leads to entrepreneurial activities in the form of demonstrations [F1] which again enforces guidance of the search [F4]. This last cycle is usually weak or absent. The connection between the functions of innovation systems in the STP motor is depicted in Figure 3.5.

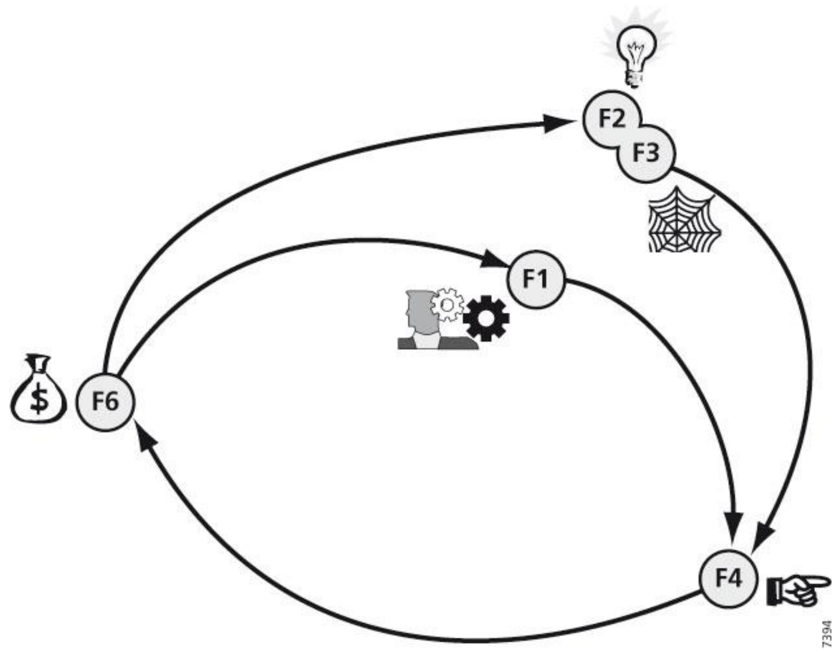


**Figure 3.5: Science and technology push motor (Suurs & Hekkert, 2010)**

The STP motor emerges with the availability of some of the following conditions (Suurs & Hekkert, 2010):

- There is an emerging technology

- There is a promise that the technology will solve certain societal problems

- There is a growing sense of urgency among a group of policy makers with regard to one or more societal problems.

- The science and industry take the role of enactors. Enactors are actors that are directly involved in the development of a particular technology and dependent on its success. Policy maker makers on the other hand are selectors. Selectors are the actors that can choose between different options which does not make them dependent on the technology in question.

***The entrepreneurial motor***

This motor is a lot like the STP motor. However it is different in the fact that the entrepreneurial motor is strongly dependent on Support of advocacy coalitions [F7] and Entrepreneurial activities [F1]. Usually the entrepreneurial motor starts with firms, utilities or local governments initiating innovative projects [F1] in the form of demonstrational projects or experiments. They initiate these projects because they see opportunities for financial gain in the future, so there is guidance of the search [F4]. Because the technology they are looking to gain profits with is still in a pre-commercial status, the entrepreneurs lobby the government to cover their risks [F7]. When they succeed in attaining the government's support, financial support in the form of i.e. subsidies is granted to the entrepreneurs [F6]. Projects can then be started, and depending on their success, other initiators start new projects or decide to look for other alternatives [F4]. The Entrepreneurial motor is depicted in Figure 3.6. This figure also shows that the dynamics of this motor can be strengthened by the existence of niche market activities [F5].These small markets are usually not part of the TSIS, but they can take advantage of opportunities that arise due to the creation of the TSIS. These opportunities lead to more positive prospects for the technology of the TSIS [F4] and therefore this in turn leads to more entrepreneurial activities [F1]. The connection between Entrepreneurial activities [F1] and knowledge development and diffusion [F2, F3] is because feasibility studies are being done for the entrepreneurs and entrepreneurs in their turn can provide information gained through learning by doing.

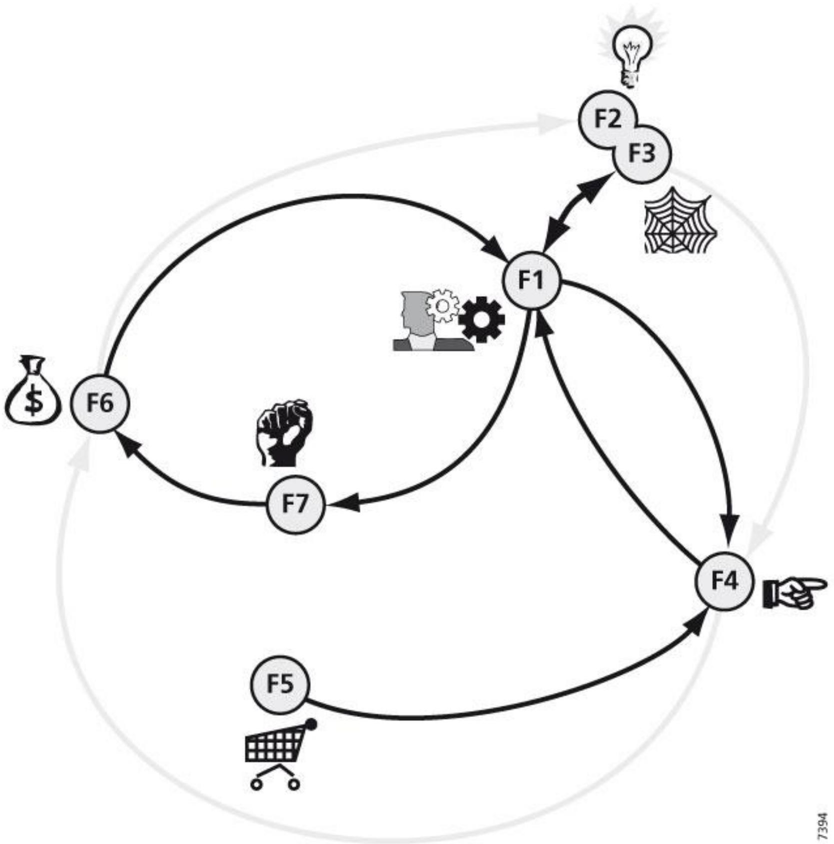


**Figure 3.6: The entrepreneurial motor (Suurs & Hekkert, 2010)**

Typical conditions for the emergence of the Entrepreneurial motor are (Suurs &Hekkert, 2010):

- The presence of a relatively developed but pre-commercial technology which is poorly aligned to the present institutional structures.

- The promise of a commercial environment for the technology.

- (Local) governments and intermediaries are willing to help firms with projects in the form of subsidies.

- Firms and utilities take the position of enactors. They initiate the development and encourage adopting of the technology

- Governments and large firms at as selectors by building institutions and by serving as launching customers.

***The system building motor***

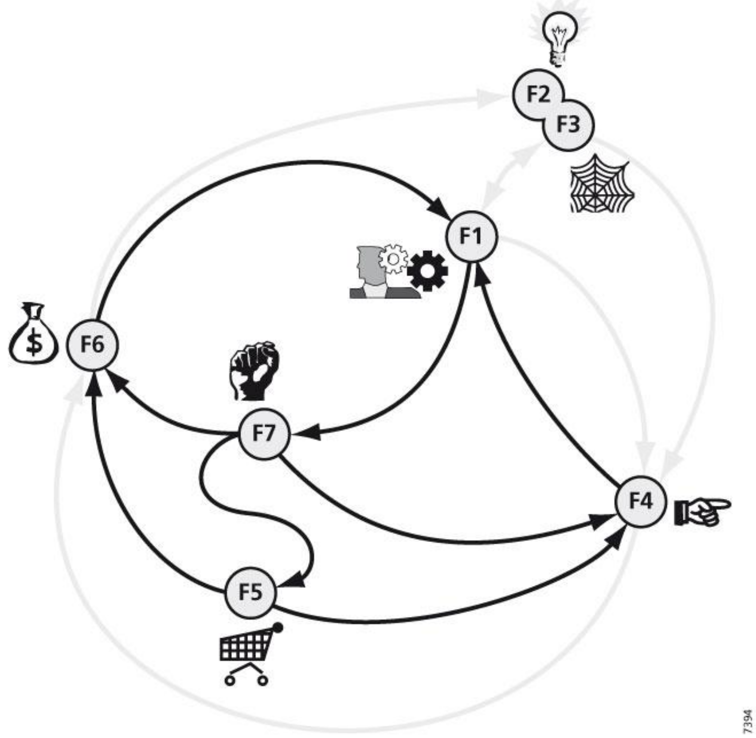


**Figure 3.7: The System building motor (Suurs & Hekkert, 2010)**

This motor comprises all TSIS functions. The most important addition compared to the two previous motors is Market formation [F5]. This motor is characterized by entrepreneurs who organize themselves in networks [F1, F3] through which they can effectively lobby the government [F7]. The lobbying is aimed to mobilize resources and to develop powerful institutions that support the TSIS as a whole [F4, F6]. The principal aim of the networks is to create a mass market [F5] for the emerging technology. The outcome of this lobbying affects the guidance of the search [F4] and resource mobilization [F6] which in their turn affect the entrepreneurial activities [F1]. Figure 3.6 depicts the System building motor. It shows the connections between [F1] and [F7] which influence [F4, F5, F6]. [F4] and [F6] again affect [F1]. Market formation [5] also affects [F4] and [F6]. The picture shows that the Markets [F5] do not exist beforehand but are created and shaped by the TSIS. The picture also shows that the System building motor overlaps with the Entrepreneurial motor as there are still a lot dynamics from the entrepreneurial motor that can be found in the system building motor. In fact, the vast network that lobbies the government is created first by the Entrepreneurial motor.

The system building motor is characterized by the following conditions:

- The presence of a near mature technology beyond the stage of demonstration.

- The promise of a commercial environment for this technology.

- The enactors have organized themselves into networks with enough political momentum to take on firms and government structures.

- Several selectors are willing to invest in marketing and infrastructure.

- End-users are becoming important, usually in a selector role.

***The market motor***

All system functions are strongly fulfilled in this motor except for Support from advocacy coalitions [F7]. This is because Market formation [F5] is no longer an issue of politics. A market environment has then already been created as a result of formal regulations. Market formation [F5] has become a regular activity flowing out of marketing and promotion strategies linked to entrepreneurial activities [F1]. In other words, there is a market and the regulations support this market and make it possible for it to expand even more through new activities initiated by entrepreneurs.

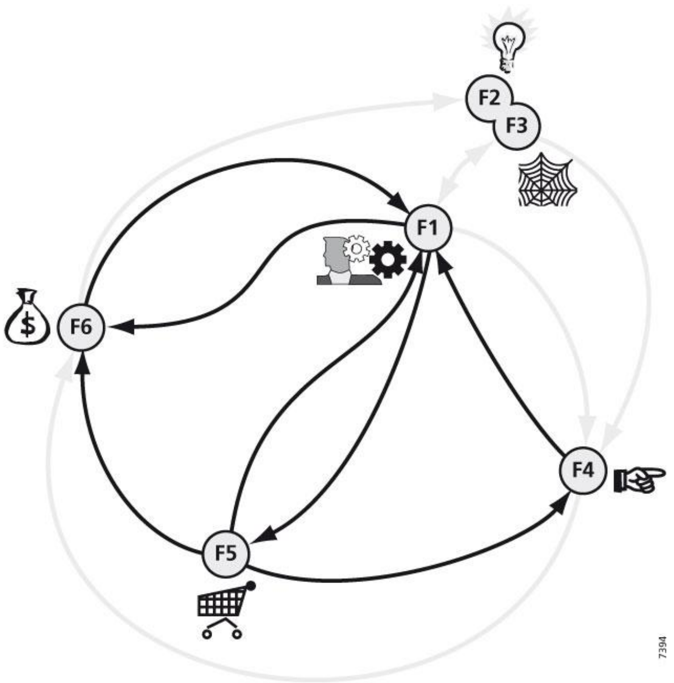


**Figure 3.8: The market motor (Suurs & Hekkert, 2010)**

The market motor starts by the setting up of institutional structures that facilitate the commercial demand for the emerging technology [F5]. This leads to high expectations [F4] and an increase in the availability of resources [F6]. This leads to new opportunities for new entrants to use the technology [F1]. These new entrants make large investments [F6] and create more opportunities for the emerging technologies [F5].

The market motor is depicted in Figure 3.8. It shows that there is a strong connection between [F5] and [F1], between [F4] and [F1]; and between [F6] and [F1]. As lobbying is no longer of great importance, most relations between investments and opportunities are between firms, for example between entrepreneurs and banks. The figure shows also that there is still a connection with [F2] and [F3] which can be explained by the dynamics within the previous motors (information between entrepreneurs etc.).

The market motor has some of the following characteristics:

- The technology is reliable enough to be diffused throughout the energy system.

- There is a commercial market environment constituted by formal institutions.

- New actors become part of the enactor group. Selectors become closely linked to the enactors and supportive of the emerging technology including incumbent firms, the government and end-users.

- There is such a strong momentum within the TSIS that external resistance can be overcome.

***Motors of decline***

As motors of sustainable innovation can lead to the buildup and expansion of a TSIS, it can also lead to breakdown of a TSIS. A negative event in one function of a system can lead to negative effects on the other functions. In this case the motor becomes a series of events that can lead to the accelerated breakdown or destruction of a TSIS.

Motors of decline usually occur with the availability of the following conditions:

- The presence of overstretched expectations. Usually created by enactors and supported by a few selectors.

- The range of technologies and institutions supporting the technology is narrow.

- Increasing distrust among selectors as a result of disappointing outcomes.

- Selectors are subject to a shifting institutional environment that makes them reject the technology in favor of other priorities.

## 3.3 Chosen framework

This paragraph will explain which framework is going to be used in this thesis. Each of the models discussed in paragraph 3.2 will be evaluated based on the criteria explained in paragraph 3.1. The fulfillment of each model to the criteria is stated in Table 3.1. Furthermore, this paragraph elaborates a little more on the reasons behind the selection of the framework.

| | Porter's Diamond | The Multilevel model | Large technical systems | National Systems of Innovation | Sectoral Systems of Innovation | Technology Specific Innovation Systems |
|---|---|---|---|---|---|---|
| **Technology specific** | | ✓ | | | | ✓ |
| **Multi-actor environment** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Dynamic analysis** | | | ✓ | ✓ | ✓ | ✓ |
| **Considers factors that are difficult to influence by actors** | | ✓ | | | | ✓ |
| **Possibility to apply on a large time span** | | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Focus on diffusion of technology** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Focus on R&D** | | | ✓ | ✓ | ✓ | ✓ |

**Table 3.1: Selection criteria fulfillment of theoretical models**

Porters Diamond framework explains why certain industries in certain nations are successful. The focus is mainly on firms and their market interactions within their environment, which is mainly within the borders of a nation. The framework lacks focus on development of the products produced by the industry. As Table 3.1 already indicates, the Diamond model is not suitable for this thesis.

Large Technological Systems, as the name already implies, considers systems that are mainly defined by a vast interconnection of technological artifacts. The Electricity grid or telephony network are good examples. It is not about one technology, but many different technologies that need to be applied and aligned to satisfy the system's goals, which in case of the electricity system would be delivering electrical energy. As this thesis only considers one technology (each of the PV technologies) this framework cannot be applied for the analysis.

The national system of innovation and the sectoral system of innovation concepts cannot be applied because these two explain how development and diffusion in general are dependent on the structure of these systems. As this thesis only analyzes the development and diffusion of one specific technology or one field (PV), many factors of the aforementioned systems are not relative or some factors are just missing.

The strength of the Multi-level perspective is that is explains innovation or technological transition by the interplay of stabilizing mechanisms at the regime level and regime-destabilizing landscape pressures combined with the emergence of radical innovations at the niche level (Markard, 2008). However is does not go into depth about the interactions and strategies of the actors involved.

The Technology Specific Innovation System framework on the other hand, is not necessarily bounded by national or regional borders or one specific sector. Market and non-market interaction play a significant role as well as regulations, values and other non-technological factors described by the Multi-level perspective as Regime and Landscape. This makes this type of Innovation System framework more outwards oriented than other Innovation Systems which do not pay a lot of attention to the environment around the system (Markard, 2008). Functions of innovation systems make it possible to map all relationships between the different actors in a dynamic way. This gives a better insight in the strategies, goals and importance of all actors, which in turn gives better explanations for changes within the system. Combined with the identification of virtuous and vicious cycles by identifying the different motors of innovation, a dynamic analysis can be made.

The TSIS approach is also presented by scholars as suitable for the analysis of competition between technologies (Hekkert, 2007; Carlsson & Stankiewicz, 1991). This is because there are more than just technological aspects that determine the success and competitiveness of a technology. There is a whole system behind its success; and the TSIS zooms in on the system for each specific technology by considering both technical and social aspects.

The framework used in this research is therefore the TSIS framework using functions of innovation systems to analyze the dynamics within the TSIS. The analysis will be done for the TSIS of PV technologies within the Netherlands. The framework is depicted in Figure 3.9.

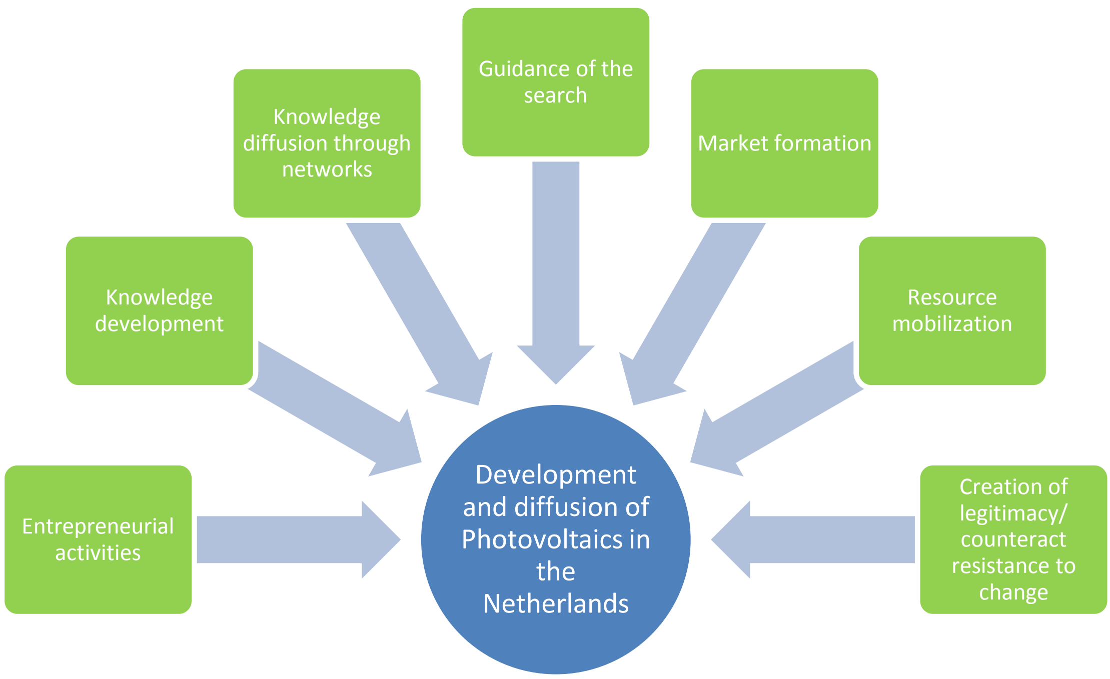


**Figure 3.9: Theoretical framework**

## 3.4 Indicators

Some of the indicators mentioned in paragraph 3.2 are not available for all PV technologies in the Netherlands. Therefore, some of the indicators have been left out. This mainly holds for quantitative indicators that are difficult to analyze within the time scope of the thesis and considering the availability of the information. This is especially regarding Function 6. It is very difficult to acquire information about each and every investment ever made. Difficulty of acquiring data over time regarding resource mobilization was also acknowledged by Hekkert (2007).

A lot of data (like employment) did not make a difference between the technologies but were only available for PV in general. Contacting the source of the information also did not lead to further details. Statistics Netherlands (CBS) who collected the information did not differentiate between the PV technologies. Furthermore, some functions have been analyzed with indicators that seemed relative but were not explicitly mentioned in literature. This is mostly for the case of function 5. Because, as will become clear throughout the thesis, most production takes place for foreign markets, taking the export and import into account seemed necessary to create an image of the market formation.

Some indicators were so related that information seemed to be repeated. Therefore in Function 5, to avoid unnecessary repetition of information instead of just mentioning certain financial market incentives, the consequences of these incentives were explained. This was because Function 4 and 6 already describe what financial incentives were available. Mostly qualitative indicators have been used regarding the time scope of the research. The used indicators are showed in Table 3.2.

| **Function of Innovation Systems** | Indicators |
|---|---|
| Function 1: Entrepreneurial activity | - Type of entrepreneurs<br>- (Number of and increase in) entrepreneurs per type<br>- Future plans for companies<br>- Availability of complementary technologies |
| Function 2: Knowledge development | - Research done per technology<br>- Defining which actors are performing the research |
| Function 3: Knowledge diffusion through networks | - Available collaborations and consortia<br>- Assessing formalized exchange methods<br>- Assessing Collective (research) projects |
| Function 4: Guidance of the search | - Targets and expectations set by the government and how they reacted because of that (taxes, subsidies…)<br>- Targets and initiatives of companies<br>- Technological expectations |

| | |
|---|---|
| Function 5: Market formation | - Assessing how the technologies were first used (niche markets) and who the users were<br>- Assess the effect of subsidies on market formation<br>- Assess how the market was protected<br>- Assess where the market was located (home market or export) and where the products came from (import) |
| Function 6: Resource mobilization | - Assess the funding of research and demonstration projects<br>- Assess the financial stimulation of the market<br>- Assess the availability of raw material<br>- Employment |
| Function 7: Creation of legitimacy/counteract resistance to change | - Assess the existence of advocacy coalitions and their activities.<br>- What were the targets of the lobbying activities?<br>- Assess the results of the advocacy coalition's activities |

**Table 3.2: Used indicators for the Functions of Innovations Systems**

# 4. The functions of IS analysis

In this chapter the functions of innovation systems for each of the PV technologies selected in paragraph 1.4.2 are going to be analyzed. First, an overview of all important actors of the PV innovation system is going to be presented in paragraph 4.1. Then, each Function is going to be analyzed in a separate paragraph of this chapter.

## 4.1 Companies and research facilities

There are different actors involved in PV regarding the different technologies. In this paragraph they are going to be divided into: Companies, Research facilities, Research institutes, Universities, Governmental agencies and foundations, involved ministries and the users. The companies discussed in this paragraph are the ones that were encountered most during the research in articles and during interviews. There are more companies occupied with installation and also new companies that have not been very active in the innovation system yet. These will be mentioned in the next paragraphs but have not played a very significant role (yet) and are therefore left out in this paragraph.

### Companies

**Solland Solar** (www.sollandsolar.com)

This company is a solar cell and module manufacturer founded in 2003. It is a 100% subsidiary of a Dutch multi-utility company called Delta. They manufacture multi-crystalline silicon solar cells and Back-contact multi-crystalline cells based on “metal wrap through” these cells are called “Sunweb” cells and can reach efficiencies of 17%.

**OTB Solar** (www.otb-group.nl)

OTB Solar is a manufacturer of solar cell production machines. It is a 100% subsidiary of OTB group which is a tailor made machine manufacturer. OTB solar became a separate business unit in 2004. OTB group was founded in 1994 and they started manufacturing machines for solar cell production around 1999 (for Shell Solar). OTB Solar is now specialized in the manufacture of production machines for crystalline silicon solar cells and antireflective coating that improve their efficiency (Solar Magazine, 2010).

**Scheuten Solar** (www.scheutensolar.com)

This company started around 2000 and is headquartered in the Netherlands (Solar magazine, 2010). The production facilities are in the Netherlands and in Germany; and they are represented in several European countries as well as in the United States. This company is specialized in the manufacture of solar panels and building-integrated solutions. The company has production facilities for crystalline Silicium in Germany and started a pilot factory for CIS solar cells in Venlo.

**Ubbink Solar** (www.ubbink.nl)

This Solar panel manufacturer and is a subsidiary of Ubbink-Group which manufactures building facilities like ventilation, lightening etc. The panels they make are made of crystalline silicon solar cells.

**Nuon Helianthos** (www.nuon.com)

Nuon Helianthos is a company that aimed to produce thin film amorphous silicon by a Roll-to-Roll manufacturing process. It is since 2006 a full subsidiary of Nuon but it already started laboratory research on thin-film amorphous silicon production around 1997. At the time, the company was a joint venture between Shell and Akzo Nobel. At the end of 2004, Shell decided that the joint venture did not fit in their strategy anymore and decided to end it (ter Beek, 2006). Akzo Nobel did not see the amorphous silicon solar cells as their core business and decided to sell the technology to Nuon around 2006. The Roll-to-Roll process used by Nuon Helianthos was meant to make the production process of solar cells cheaper and thereby being able to compete with fossil fuels. The solar cells were produced in a “trial” factory. When the process would prove to be successful, a real factory would be established, in Arnhem. Because Nuon could not find investors for Helianthos, the subsidiary was closed down in 2011.

**Oskomera Group** (www.oskomera.nl)

This is a group of companies that engineer, develop, manufacture and install windows, walls and load-bearing constructions in aluminum and steel. They operate in Europe and the Netherlands Antilles. In recent years they have specialized in solar power. They realized many projects in the Netherlands involving Photovoltaics.

**Solar Plaza**

This is a private company based in Rotterdam and was founded in 2004. It functions as a global platform for knowledge, trade and events for the PV industry.

**Smit Ovens**

This company designs and manufactures thermal process solutions for high volume manufacturing. They are specialized glass, displays, electronics and solar applications. They manufacture equipment that is part of the process to produce CdTe and CIGS solar cells. They also manufacture equipment to make TCO which stands for Transparent Conductive Oxide. This technology is used limit the losses on the incoming light that hits the solar cells (Solar Magazine, 2010).

**Tempress Systems** (www.tempress.nl)

This company develops and manufactures vertical and horizontal Diffusion & Low Pressure Chemical Vapour Deposition furnaces for i.e. semiconductor and Solar industries. They produce fully automated furnace systems to produces semiconductor wafers. For the solar industry they manufacture production machines for crystalline silicon cells and anti reflective coatings.

## Intermediary organizations

**Holland Solar** (www.hollandsolar.nl)

This is an organization that promotes and lobbies solar energy in the Netherlands. It is especially focused on the end market. These are PV system installers.

**Zonnestroom Producenten Vereninging** (www.zonnestroomproducenten.org)

This is a consumer organization that looks after the needs of producers of sustainable energy; this can be PV or other sustainable energy like wind.

## Research institutes

**Energy research Centre of the Netherlands (ECN)** (www.ecn.nl)

ECN develops knowledge and technology for the transition to sustainable energy management and introduces its knowledge and technologies to the market. In the field of PV, they have expertise in the technology of Silicon materials, back contact module technology, thin-film silicon and organic based PV. They are also specialized in environmental profiling of PV.

**TNO** (www.tno.nl)

This is an independent Dutch research organization. The research they do is in a variety of technological fields for various customers varying from companies to governmental organizations. They collaborate with, among others, ECN and Imec, a Belgian company, on the research on PV technologies. TNO has been involved in several PV technologies over the years.

**Holst centre** (www.holstcentre.com)

This is an independent open-innovation R&D centre located in Eindhoven that develops technologies for wireless Autonomous Sensor Technologies and Flexible Electronics. It has strong relationships with the industry and academia. It was set up in 2005 by Imec and TNO with support from the ministry of economic affairs.

Holst Centre offers research programs on Roll-to-Roll organic Photovoltaics in collaboration with ECN.

## Universities

- *Delft University of Technology*

- *Eindhoven University of technology*

- *University of Utrecht*

- *Rijksuniversiteit Groningen*

The universities are doing researches in many PV fields from materials to production technologies. They also collaborate. For example, the "Helianthos" consortium was formed by the first three universities, TNO and Akzo Nobel. This was before Helianthos became a 100% subsidiary of Nuon (www.kennislink.nl).

## Government agencies and foundations

**The Netherlands Organization for Scientific Research** (www.nwo.nl)

This is an organization that funds researchers at universities and institutes and steers the course of the Dutch science by means of subsidies and research programs. Most of the financial resources of NWO come from the Ministry of Education, Culture and Science.

**Foundation for Fundamental research on Matter (FOM)** (www.fom.nl)

This foundation promotes co-ordinates and finances fundamental physics researches in the Netherlands. Its annual budget is 94 million Euros with which they also finance research on Photovoltaics. Amolf, is one of the research laboratories of FOM where fundamental research is done on complex atomic and molecular systems with key potential for technological innovation.

FOM is mainly financed by NWO, subsidies from the government and payments for assignments performed for others (FOM annual report, 2010).

**SenterNovem**

SenterNovem is a government agency that was formed by a merger of the two government agencies Novem and Senter in 2004, both government agencies of the ministry of economic affairs. Later on Senternovem became part of Agentschap NL after merging with EVD and The Netherlands Patent Office.

The focus of SenterNovem, now Agentschap NL, is on sustainability, innovation, international business and cooperation. It serves as a contact point that provides information, financing, networking and regulatory matters for companies, knowledge institutions and government bodies. SenterNovem is responsible for the government's investments when it comes to PV.

## Ministries

**Ministry of Economic Affairs, Agriculture and Innovation**

AgentschapNL function in order of the Ministry of Economic Affairs, Agriculture and Innovation. The ministry defines budgets and regulations and AgentschapNL has to apply them.

**Ministry of Education Culture and science**

NWO receives most of their funding from this ministry. This way this ministry is involved with PV but only on the field of fundamental research.

**Ministry of Housing, Spatial planning and the Environment**

A PV panel can be installed without any permits when it meets safety and appearance regulations. The panel should for example not be sticking out on the side of a roof. And when the roof is flat, the panels should be at a safe distance from the edge of the roof. The Ministry of Housing, Spatial planning and the Environment defined these regulations.

This ministry was also in charge of a subsidy called EPR initiated in 2001. In 2003 this subsidy was halted and new subsidies like SDE became the responsibilities of the ministry of Economic Affairs, Agriculture and Innovation.

## Users

In paragraph 4.6, Function 5 will describe the market for PV technologies and hence the users. The first PV systems were autonomous and not connected to the grid these were used for garden houses, drinking troughs and buoys. The applications did not need a lot of energy and connecting them to the grid would need a lot of money. Most of these systems have been installed without any subsidies (kruijsen, 1999). That is because most systems were small and were already cost effective for their applications.

When connection of PV systems to the grid became possible, everybody with a connection to the grid could install a PV system to save money on their energy bill. Energy companies (utilities) also installed larger PV systems to produce sustainable green energy and attract clients this way. As can be noticed in Figure 4.6.1, most of the installed systems in the Netherlands are private grid connected systems and a small part is installed by energy companies. There is a small amount of autonomous systems which decreased over the years.

Users consist of individuals, businesses, municipalities and utilities. Most grid-connected users up till 1999 owned systems that were installed under demonstration projects that mainly relied on subsidies (Kruijsen, 1999). Many systems installed after 1999 would not have been realized without subsidies either. More details on subsidies and their effects are discussed in Functions 4, 5 and 6.

The first projects during the nineties were realized by initiation from energy companies (utilities). Their goal was to get experience with the technology because they saw potential in the market (van Mierlo, 2002). This business model was too expensive and customers wanted to own the systems installed on their houses. Therefore, the utilities turned to selling the panels to their clients. Most PV systems were applied on new buildings by project developers in order of the initiators. These PV systems were easier to sell because the price could be hidden within the price of the houses; and it made the houses more attractive with a green image.

At the moment most PV systems installed in the Netherlands are installed on houses (CBS, 2009; AgentschapNL year review, 2010).

## 4.2 Function 1: Entrepreneurial activity

Entrepreneurial activity takes place in different parts of the value chain of Photovoltaics. It ranges from solar panel manufacturers to cell manufacturers to manufactures of the machines that make the solar cells. This paragraph is going to set out the different entrepreneurs and will end with conclusions regarding the entrepreneurial activities for each PV technology.

### *Cell manufacturers*

The first company that started to produce solar cells was a company called Holecsol. This company was established in 1982. Later on, in 1984, this company was taken over by shell and became R&S Renewable Energy Systems (ECN, 1997). The product of the company was poly-crystalline Silicon solar cells. In 1983, Holecsol started the first big scale PV project in Terschelling with help from the Dutch ministry of economic affairs and the European communities (Verbong, 2001; Lysen, 2006). The project was initiated to provide a nautical college with a fully autonomous sustainable energy power supply system consisting among other energy sources of wind energy and PV. The PV system supplied 50 KW.

Holecsol became R&S and was the only company involved in PV together with three other companies called Stromag, Solpro and Zontechnologie. The last three companies do not exist anymore and no information could further be found about them. Since R&S is the only cell and panel manufacturer the others were perhaps involved in distribution or related technologies. Together they made a revenue of 10 million guilders in 1985. Only 20 % of the revenue was made in the Netherlands (Verbong, 2001). Ten years later, in 1995 Shell invested 6.5 million guilders in a new poly-crystalline production line of R&S. Shell proved with this investment to be interested in the development of solar cells.

In 1996, ECN defined four important technologies which were on the market or were back then soon to be commercially available. Mono- and multi-crystalline silicon solar cells were already being sold. Amorphous silicon solar cells were also commercially available. CdTe and CIS solar cells were still in the laboratory phase and were expected to be commercially available by the end of that year (van Hilten, 1996). The report of van Hilten also suggests that in 1996 there was only one cell producer which was R&S. As this company only produced crystalline silicon solar cells, it means that amorphous silicon solar cells were still not being produced in the Netherlands in 1996.

The market for solar cells in the Netherlands was dominated by Shell solar until 1996, after taking over R&S. In the few years that followed, Shell Solar started to lose ground to several foreign market players like Kyocera and BP Solar (Roos, 2001). In 1997, many large scale projects were going on. These projects were aiming at showing the possibilities with grid connected PV systems (EVN, 1997). Projects as those of Amsterdam Nieuw-sloten (250 kWp) and Amersfoort Nieuwland (150 kWp) were almost entirely realized with solar panels from Shell solar (PV database, 2011) which were at that time made of crystalline silicon solar cells. The projects were financially supported by Novem.

In 1999, Shell solar was still the only Dutch producer of solar cells and panels. Akzo Nobel announced around the same year that they were about to start a pilot line for the production of amorphous silicon solar cells in 2002. It was expected that the products would then be market-ready around 2005.

In 2000, Shell had a cell production capacity of 4.5 MW and their panel capacity was announced to be expanded by 15 MW. Meanwhile they announced to increase their production capacity in Germany by 25 MW a year (PVPS, 2000). In 2001, after a merger with Siemens Solar, the production focused even more on Germany and the announced expansions in the Netherlands in 2000 were not realized (PVPS 2000, PVPS 2001). Another player showed up in 2000, this was Scheuten Solar. Even though Scheuten Solar was a Dutch company, the production mainly would take place in Germany a few years later producing crystalline silicon panels. In 2001, they came up with the Sunrise technology which is a CIS technology. The pilot line for that technology was opened in 2007 (Jäger-Waldau, 2007).

In 2002, Shell Solar produced 7300 KWp of poly crystalline solar modules. 900 KWp of the solar cells used in these modules were manufactured by Shell Solar facilities in the Netherlands, the rest were produced by Shell facilities abroad like in Germany. In 2002, Nuon managed a project to make the biggest rooftop PV installation. This was on the roof where the Floriade was organized, a horticulture exposition (Negro, 2008; Floriade brochure, 2002). Shell Solar delivered the cells which were mono-crystalline silicon cells and the power produced by these cells could be 2.3 MegaWatt, comparable to the energy use of 450 households. In 2003, Shell Solar decided to leave the Netherlands because of insufficient demand (van Beek, 2003).

In 2003, Solland Solar was established. By 2006, Solland Solar was the only manufacturer of solar cells, producing poly crystalline cells. Ubbink Solar was then the only PV module manufacturer in the Netherlands and used poly crystalline solar cells in their products. Ubbink got the cells for their panels from Solland Solar (Pruissen, 2011). The production line of Scheuten Solar started the same year producing mono and multi crystalline solar panels in Germany (Scheuten Solar website). Most projects of Scheuten have been realized in Belgium and Italy during the first half of 2011 (Scheuten Solar website, 2011).

Solland Solar was quite successful between 2006 and and 2009 initiating several production lines of 40 MW in 2007 and 110 MW in 2008.Their biggest customers are in Germany. They have two customers in France and three in Italy (Dicken, 2011). In 2006, Scheuten Solar initiated a pilot production plant for CIS cells (Scheuten Solar, 2011). Industrial production for that technology has not taken off yet.

Even though Nuon Helianthos had not started their amorphous silicon production line in 2004, a parking garage in Zwolle installed 840 amorphous silicon solar panels. This means that amorphous silicon solar cells were used in the Netherlands even though they were not locally produced. These panels were however not flexible like the ones researched at Nuon Helianthos (Novem, 2005). There was a Dutch company involved in amorphous silicon panels called Free Energy Europe. The amorphous silicon panels for this company were manufactured in France and they sold to developing countries (van der Vleuten, 2011). According to van der Vleuten, the former owner of Free Energy Europe, the market share of amorphous silicon panels in the Netherlands is negligible. Free Energy Europe was sold to another company called WWE Sustainable Solutions. This company initiated a subsidiary company in France but the latter went bankrupt in 2010.

In 2009, Nuon Helianthos started their long awaited production line of amorphous silicon solar cells. Still, the production line was for demonstration purposes and not yet ready for large scale industrial production. This kept Solland Solar the only industrial producer of solar cells in 2009. Nuon

Helianthos was up till now not selling their amorphous silicon solar cells (Nuon website). They were still optimizing their production technologies. Whether they were ever going to produce on large scale is doubtful (Soppe, 2011; van der Vleuten, 2011). In fact, they were closed down in September this year (2011)[Nuon website]. Solland Solar on the other hand underwent a management take over (van der Gugten, 2011; Dicken, 2011). Solland Solar is now thinking of changing from cell manufacturer to panel manufacturer. It is not sure yet whether the cells for those panels will be made at Solland or imported (Dicken, 2011). By making panels they forecast they will have a bigger market as they are closer to the end user.

CdTe solar cells are not produced in the Netherlands and cannot even be used in the Netherlands. This is perhaps due to regulations regarding the use of Cadmium in consumer products. The use of Cadmium on metal surfaces is prohibited according to European regulations (Wentink, 2001). Even though CdTe solar cells do not fall under this regulation because CdTe is deposited on a conducting oxide layer, the use of cadmium holding solar cells is forbidden. This holds for CdTe cells and some cadmium containing CIGS cells. However CIGS do not necessarily need to contain Cadmium.

### *Solar Panel manufacturers*

At the beginning, Shell Solar (Holecsol and R&S) was the only company providing solar panels next to solar cells. Philips also joined in 2002 with poly-crystalline silicon solar cells (IEA, 2009).

Ubbink Solar was the only PV panel manufacturer in the Netherlands until 2010 (Pruissen, 2011). Ubbink Solar produced panels based on multi-crystalline solar cells (Ubbink, 2009). In 2006, they had a production capacity of 10 MW (IEA, 2006). Ubbink Solar started as “Ubbink Solar Modules”. This company was situated in the building of a company called Ubbink which is active in the construction industry. Ubbink Solar Modules was back then not a subsidiary of Ubbink but of part of another company called Centrosolar. Ubbink Solar Modules almost had to close down their PV module production facility in 2009 because their main customer (Ecostream) who bought 85% of their products went bankrupt (Kema, 2010). Ubbink then decided to take over Ubbink Solar Modules and it became Ubbink Solar (Pruissen, 2011). Eneco took over the activities of Ecostream in supplying solar panels among others to the Belgian market (nu.nl, 2009; Pruissen, 2011). Ubbink Solar now sells about 10 Mega Watt of PV systems a year worldwide of which 0.5 Mega Watt a year in the Netherlands (Pruissen, 2011). The export is mainly to European countries like Germany, France and Italy. Ubbink Solar exclusively bought their cells from Solland Solar but that changed since 2009 as the prices of cells from Asia became cheaper (Pruissen, 2011).

In 2010, a second PV panel manufacturer for c-Si panels was established. This company is called Solar Modules Nederland and has a capacity for 25 MW a year (Solar Modules Nederland, 2011).

### *Producers of cell manufacturing machines*

The Netherlands are very active on the world market when it comes to solar cell manufacturing machines. Mostly companies specialized in Thermal solutions for which the solar cells industry became a lucrative market regarding their expertise in the field of furnaces and machines that work under high temperatures. Companies like OTB –Solar provide the new solar cell market leaders like China and Taiwan with equipment to manufacture poly-crystalline solar cells and other efficiency improving technologies like anti-reflective coating (OTB Solar website).

Smit Ovens manufactures equipment that fulfills parts of the process to produce CdTe, CIGS solar cells and in a less extent amorphous silicon cells (van der Gugten, 2011). Many of their customers involved in amorphous Silicon quit their activities; and therefore the demand for a-Si equipment went down. They also manufacture equipment to make TCO which stands for Transparent Conductive Oxide. This technology is used limit the losses on the incoming light that hits the solar cells (Solar Magazine, 2010). According to an interview with the CEO of Smit Ovens that can be found on the website of Smit Ovens, competition can be considered negligible for the moment because the demand for the manufacturing technologies exceeds the supply by far. Smit Ovens started the production of machines related to the production PV cells around 2004. This was when the business for TV screens collapsed due to the emerging flat screens (van der Gugten, 2011). However, they started to look into the possibilities for PV in 2001. Smit Ovens export their products mainly to Asia and America.

Tempress who manufactures equipment that applies the doping with Phosphor and Boron to c-Si wafers is occupying the highest market share of 40% in that field (PV-Tech.org, 2011). Tempress has been active in PV for about 20 years (Scholing, 2011). They started with projects for Shell and BP. The last couple of years the demand for the products of Tempress has risen by 100% a year. Most of the demand comes from China and Taiwan.

## *Future plans for companies*

The market for PV is very dynamic, many companies were established and some of them quit their activities. There also many companies on the agenda:

**RGS Industrial**

ECN started a company called RGS Development together with the company Sunergy Investco and the German company Deutsche Solar. RGS Development is working on a pilot plant to produce cells made by the production technology of Ribbon Growth on Substrate. With this technology poly crystalline silicon cells can be produced faster and with less material loss. More on this technology is explained in the paragraph of Function 2. The goal of ECN and its partners was to start the company RGS Industrial where the cells will finally be produced on industrial scale. The pilot plant is expected to be productive around 2012. ECN is not a partner in this project anymore (Weeber, 2011). Even though RGS might be a cost saving solution, it is not as standardized as the usual wafer production by sawing silicon ingots. This makes the future of this technology unsure.

**The Silicon Mine**

In Sittard-Geleen in the province of Limburg, a factory for the production of silicon grade will be established. Silicon grade is the material out of which silicon wafers can be produced. The factory is expected to be active in 2012. Contracts for investments with many parties have been signed; one of the most striking investors is an investment company from Abu Dhabi financing the project with 200 million euro. The total project is expected to cost about half a billion euro. The production is expected to reach 6000 ton a year and even 20.000 on a longer term (The silicon mine, 2011). Several wafer producers have already signed agreements to buy the silicon grade for a period of 10 years.

**Supercis**

This recently established company will look into the possibilities to develop and exploit the mass production of CIGS (van der Vleuten, 2011).

## *Complementary technologies*

Perhaps the most important part of the PV system after the module is the inverter. This device turns the DC current supplied by the PV module into an AC current that can be used for home appliances, which usually function with AC current. There are several manufacturers of inverters in the Netherlands, for example Philips, Mastervolt, Exendis and NKF (ZPV, 2011). A shortage or lack of complementary technologies has never been the issue in the Netherlands because this problem was never encountered during the research nor did any of the interviewees mention it. What did form a problem was that inverters were a kind of the weak link in a PV system as users had many problems due to malfunctions (Wouterlood, 2011; ZPV, 2011). One of the reasons for this was the lack of experience of some installers (ZPV, 2011; Veenstra, 2011). To illustrate, some panels installed had a much higher power capacity than the inverter could take. This goes unnoticed when it is not sunny, but when the modules deliver at full power the inverter breaks down. Sometimes the inverter itself is the problem due to technical problems. This happened to some systems delivered by Nuon and Eneco containing NKF inverters (Wouterlood, 2011).

## *Conclusions Function 1*

**Crystalline silicon solar cells**

Crystalline silicon solar cells are the only cells that are being produced in the Netherlands. There has always been one cell producer of this technology though. First the company that later became Shell Solar and then Solland Solar took over the cell production in the Netherlands. The only panel manufacturer has been Ubbink Solar until 2010; then, a second player came to the market. Ubbink Solar bought their cells exclusively from Solland Solar for a long time but that changed as their prices became higher than the cells from Asia. This shows that it became difficult to compete on the solar c-Si cell market because of the Asian producers. That can also be concluded from the fact that Solland Solar is thinking to turn to solar module production instead of (only) cells and the fact that they underwent a management buy-out.

The production has always been more focused on the foreign markets like Germany. The demand in the Netherlands was so low that Shell Solar decided to merge with Siemens Solar and focus entirely on the German market. Ubbink Solar sells about 5% of their panels in the Netherlands.

**Amorphous silicon solar cells**

Production of this technology in the Netherlands seemed possible since Nuon Helianthos had a production line. They were closed down on September 2011, which brought the number of producers down to zero. There has been a Dutch company that manufactured and sold the amorphous silicon panels abroad, so whether this company provided any impulses to the PV innovation system is questionable.

Smit Ovens provided solutions for a part of the process for a-Si manufacturing but the worldwide demand for that is decreasing because many of their customers left that business.

### CIS and CIGS solar cells

No records could be found on demonstration projects or products being sold in the Netherlands using CIS or CIGS. However machines to make these technologies are being made in the Netherlands and sold abroad. These manufacturing technologies are quite successful on the world market.

Scheuten Solar started a pilot production line around 2006 to produce CIS. Large scale production and sales have not taken place yet. In 2011, a new company was established looking to develop and exploit large scale production of CIGS.

This indicates that there is a worldwide rising in demand for CI(G)S manufacturing machines as the production of CI(G)S cells is rising. Especially the machine manufacturers are profiting from this rise in demand and newly established companies are looking to enter that market now.

### CdTe solar cells

Regarding the regulations on the use of Cadmium, CdTe is not produced nor is it sold in the Netherlands. Again the only entrepreneurial activity taken place is the production of manufacturing machines for CdTe. These technologies are sold abroad. The demand for these machines is also rising significantly as the global production and demand for CdTe cells is rising.

## 4.3 Function 2: Knowledge development

This paragraph is going to analyze Function 2 of the TSIS which is concerned with knowledge development. First the beginning of the research in the Netherlands is going to be explained. Then, the knowledge development for each technology will be analyzed by dividing the learning processes into learning by searching, learning by doing and learning by using.

### *The beginning of solar cell research in the Netherlands*

The first experiments on solar cells in the Netherlands were done at Philips by a researcher called Daey Ouwens during the fifties. He used Silicon solar cells at the time (Verbong, 2001). Ouwens was given the opportunity to work on solar cells because Philips started the production of semiconductors. In the second half of the 1960's, Philips stopped the research on PV for the greater part. Ouwens thereafter went to the University of Eindhoven to study and later on to carry on his researches on PV.

In 1974, at the Technical University of Eindhoven, a group of materials science engineers started doing research on thin-film silicon solar cells in cooperation with Holecsol (Verbong, 2001). Around the same period The Chemistry Research foundation (SON, Stichting voor Scheikundig Onderzoek Nederland) initiated researches on the transformation of crystalline Silicon into amorphous Silicon and they studied the possibilities with copper indium Diselenide (CIS). The University of Utrecht started researches on the growth of crystalline and amorphous silicon.

During the eighties, the Delft University of Technology and the University of Utrecht started doing research on thin-film solar cells (ECN, 1997). They also studied the characteristics of Silicon in cooperation with the University of Amsterdam (Verbong, 2001).

ECN started their research on Photovoltaics around 1989. Shortly afterwards, ECN started a research together with R&S to create a crystalline Silicon solar cell production line (ECN, 1997).

The different laboratories were tuned in on each other in such a way that every university was doing a slightly different research to achieve the same goals. The research projects were mainly financed by FOM. The rest of this paragraph is going to describe the developments per technology and who the main actors were during the research.

## *Developments per technology*

### Crystalline silicon solar cells

#### Learning by searching

Around 1997, especially Shell (or R&S) and ECN were working on multi-crystalline solar cells in the Netherlands (EVN, 1997).

Around the year 2000, research on multi-crystalline solar cells has been focusing on metallization (providing electrical contacts), passivation (protecting the material from impurities and corrosion) and texturing to improve the efficiency of the cells. Dutch companies were working together with foreign companies to lower the cost of Silicon wafer production (PVPS, 2000). ECN started research on the Ribbon Growth on Substrate technology (RGS) in cooperation with a German company called Bayer (ECN annual report, 2000). Bayer delivered the RGS machines and ECN worked on improving the technology. Sawing the silicon wafers from ingots causes a lot of sawing waste which could have been used to produce wafers. With RGS, the melted silicon can be directly deposited on a moving substrate. This way the silicon is directly poured into a wafer form. Hence, RGS saves material and it speeds up the process. ECN already started to investigate the possibilities with RGS in 1999 (ECN annual report, 1999). Around the same period they were investigating possibilities for the deposition of Silicon nitride ( SiN ) on solar cells. SiN serves as an antireflective coating and prevents the recombination of electrons and holes. This resulted in higher efficiencies (from 13% to 16%) (ECN annual report 1999, 2000).

In 2001, R&D in the Netherlands was still mainly focused on improving multi-crystalline cells (PVPS, 2001). RGS was further investigated and efficiencies of 8.6% have been reached with that technology by ECN. Other research regarding crystalline cells has been around the improving the contacts and removing impurities from the crystals.

In 2004, the focus was on the improvement of the PUM (Pin Up Module) cell, which is a technology for back contacts. Ribbon Growth on Substrate was also, still, a very important research topic (PVPS, 2004).

In 2005, there was still research done on the decrease in the use of silicon in silicon-based solar cells. The possibilities that were investigated were combinations of different efficiency improving solutions like back side contacts and up- and down conversion of photons (PVPS, 2005). Between 2005 and 2008, the improvement of crystalline silicon solar cells remained a very important part of the Dutch PV R&D (PVPS, 2005, 2006, 2007, 2008).

At the moment ECN is still working on improvement of the silicon material and their core activities relate to the improvement of modules' efficiency (Weeber, 2011).

**Learning by doing**

In 1982, Holecsol started the production of multi-crystalline silicon solar cells. This gave the opportunity to learn about the technology while producing it. ECN collaborated with R&S (the former Holecsol) on the design and improvement of production lines for multi-crystalline solar cells (ECN, 1997).

As discussed in Function 1, Solland Solar became the only c-Si cell producer since 2003. They also work a lot with institutes like ECN (Weeber, 2011). This made the commercial application of new concepts from research possible in the Netherlands. Examples are the Pin Up Modules and the back contact cells which have been used in cells from Solland Solar; and which have been developed at ECN.

**Learning by using**

The first project where houses where connected to the grid was delivered in 1991 in Heerhugwaard (van Mierlo, 2002). During the nineties, several demonstration projects, in which especially Shell solar was involved, followed aiming at understanding the technology and proving its efficacy. Van Mierlo, 2002, described different (pilot) projects in the built environment. These projects were accomplished with crystalline silicon solar cells. The described projects faced a lot of difficulties mainly consisting of disagreements between actors resulting out of their different backgrounds. PV panel installers and architects, for example, are both involved but they knew too little of each others' activities to come to a smooth cooperation. The projects also uncovered some technical aspects like leakages on the roofs where the PV panels were mounted. Nevertheless, each project could learn from mistakes made in previous projects and that showed in the results and the way actors collaborated. A project realized in Amersfoort in 1996, and which started in 1992, provided 50 rental houses with 110 KWp of PV power. Actors in this project learned for instance from how actors communicated amongst each other in projects that started earlier in Amsterdam (1991-1996) and Apeldoorn (1991-1998). Therefore the project was monitored more intensively; and before the project started, it had to be clear that all actors involved had the same goals with the project to avoid any conflicts. The project in Amersfoort therefore made the actors more interested in PV and other projects followed (van Mierlo, 2002). Home owners on the other hand did not show interest in PV after this project because they were not the owners and did not benefit from them directly.

Projects like one in Amersfoort Nieuwland which was realized with 1 MW c-Si solar cells in 2001 provided information on how to benefit maximally from the solar panels. It provided practical information on for example how to place the panels and how far the panels should be placed away from each other to avoid heat accumulation. Actors also learned lessons regarding legal issues. For example on how to avoid conflicts with neighboring buildings which could be expanded and this way cover an important part of the sunlight. In Nieuwland, it has been legally arranged that the roofs of existing buildings should not be made higher than their actual state (Leidraad Zonnestroomprojecten, 2010).

In the Netherlands most PV applications are in the built environment (CBS, 2009; Agentschap NL year review, 2010). Databases show that most applications up till now use mono- and multi-crystalline silicon solar cells (Pvdatabase, 2011).

## Thin film silicon solar cells

Amorphous silicon cells and micro-crystalline silicon cells are produced with the same deposition technology ( Soppe, 2011). Research on thin film silicon usually means research on both amorphous and micro-crystalline silicon (Interview Wim Soppe 2011 ; Interview Miro Zeman,2011). The combination of the two materials can form so called Tandem cells. Therefore micro-crystalline silicon cells, amorphous and tandem cells that combine these two technologies are discussed under this paragraph of thin film silicon. This will also apply for the rest of the Functions of Innovation Systems.

**Learning by searching**

One of the first researches was done during the beginning of the eighties by The TU Delft (TH Delft at that time) and Holec (Verbong, 2001). The research was on finding ways to produce amorphous silicon.

In 1994 Research on amorphous silicon solar cells was focused on efficiency improvement and improvement of the stability. Cells with an efficiency of 12% have been achieved by the University of Utrecht in cooperation with Novem in 1994 (EVN, 1994). At the time, amorphous silicon was mainly used in consumer products, but announcements of companies in Japan and the U.S to produce large production lines encouraged Dutch R&D to investigate the possibilities for large scale production (EVN, 1994).

Research on amorphous silicon in 1996 was mainly on multiple layer deposition for which amorphous silicon was considered suitable. Decreasing degradation effects were also investigated (van Hilten, 1996).

In 1996 R&S focused their research on decreasing the thickness of the crystalline layers used in their solar cells. They investigated thin-film crystalline layers which were cheaper and easier to apply on big surfaces as they do not have to be produced in the form of wafers (EVN, 1996).

In 2000, research at ECN in cooperation with TU Delft, TU Eindhoven and the University of Utrecht focused on the deposition of micro-crystalline silicon on glass substrates using plasma-reactors (ECN annual report, 2000).

In 2001, amorphous silicon cells were seen as the most promising thin film candidate for industrial production in the near future (PVPS, 2001). Around 2002, the main players in the field of amorphous silicon were the University of Utrecht, Delft University of Technology, Eindhoven University of Technology, Akzo Nobel , Free Energy Europe, TNO and ECN (Sinke, 2002). This shows the interest of many actors in this technology.

In 2005,  the TU Delft was working on fast deposition techniques of amorphous silicon (PVPS, 2005). Producing a layer of amorphous silicon of 250 nanometers was executed with a speed of 0.1 nanometer per second, which made the process take about 40 minutes. Recent research at the TU Delft increased the speed to 1 nanometer per second which saves a significant amount of money for the industry. The technology used by the TU Delft called “Expanding thermal plasma chemical vapor deposition” or ETP-CVD was developed by the Technical University of Eindhoven (TU Delft website, 2011). The problem however was that this technology could only be applied under high temperatures of 350 degrees Celsius. This temperature is harmful to the amorphous silicon solar cell. By bombarding the surface with ions, the process could be applied under 200 degrees Celsius which does not harm the solar cells. The much faster deposition technology can be applied without any efficiency loss.

Other research done, also at the Delft University of Technology was focused on improving the efficiency of amorphous solar cells by tackling the so called Staebler-Wronski effect (Engineersonline, 2011). This effect, which can still not be fully explained yet, causes a significant efficiency drop during the first hours the solar cells are exposed to sunlight. By adding more hydrogen atoms to the Silane gas , with which amorphous silicon solar cells are made, the efficiencies can go up to 9% instead of 6 to 7%.

In 2009, ECN started research on the production of a roll-to-roll process for the fabrication of amorphous and micro-crystalline silicon on a flexible steel foil. When amorphous and micro crystalline silicon are combined they form a tandem cell. These cells can absorb the part of the light spectrum of both amorphous silicon and crystalline silicon (Bolt, 2011). ECN is now waiting for an industrial partner to manufacture the complete machines. The goal of ECN now is to increase the efficiency of the cells produced with their roll-to-roll process up to more than 10% (Soppe, 2011).

**Learning by doing**

In 2005, the roll-to-roll process of Akzo-Nobel was being improved. The first cells of the pilot line were produced and had an efficiency of 6%. Research continued on a next generation of amorphous silicon cells with higher efficiencies.

In 2009, Nuon Helianthos opened a pilot production line for amorphous silicon solar cells after taking over the activities from AkzoNobel. They are still working on improving the production technologies and look into new concepts like tandem cells (Stigter, 2011).

**Learning by using**

In 1993, ECN installed 1000 Wp of amorphous silicon solar cells to test the stability and compare it to poly-crystalline silicon cells which were tested under the same conditions. This was the first test with amorphous silicon having this scale (Baltus, 1993). The goal of this test setting was to acquire knowledge through learning by using. 1000 Wp produces about 850 KWh of electricity. This means that these installed panels produced about one fifth of what an average Dutch household needs. As this project was the first having this scale, and which is almost negligible, it is obvious that amorphous silicon panels were not used for power generation in many projects before 1993.

For the façade of a parking space in Zwolle, 26.88 KWp of amorphous silicon panels have been used (PVNord, 2011; Novem, 2005). The goal of the project was to show the possibilities of the technology in a country like the Netherlands and its suitability for replacing building parts like facades. The total project lasted from 1999 until 2005. The project showed that PV was very appropriate to replace parts in buildings that were initially not meant for power generation. Nevertheless, it also showed that such a project is not feasible without the use of subsidies. Out of the 313,000 euro needed for the project 48% was subsidized by Novem, the European Union and Essent (Novem, 2005). The project was realized by Oskomera and the amorphous silicon panels used were from a company called Schott Solar which is a German company (Novem, 2005).

The product of Nuon-Helianthos has up till now only been used for one project which was for the IKEA building in Duiven (Stigter, 2011).

## Organic Solar cells

### Learning by searching

Research on organic solar cells started around 1992 (van Hilten, 1996). In 1997, ECN developed the first organic, Dye sensitized solar cells in the Netherlands in cooperation with a Swiss company Solaronix that was the license holder for that technology (EVN, 1997). The solar cells had a laboratory efficiency of 11%. ECN started working on organic solar cells in 1995. In 1997, the technology was expected to be applied in small consumer products first but was considered an important candidate for grid connected power supply in the future.

ECN participated in several European projects regarding organic solar cells in 1999 (ECN annual report, 1999). The projects were mainly looking into the possibility for implementations of organic solar cells on the short term. With mainly ECN-designed technologies, Dye sensitized solar cell mini modules have been developed to be used in consumer electronics using a newly invented pilot line. Other research investigated the “bleaching” of the pigmentation of the Dye sensitized solar cells which would lead to degradation and hence a loss of efficiency. The result of the research was that only the outside of the cell suffered from these losses the heart of the cell however stayed stable. Further research investigated therefore the factors that could lead to a total stabilization of the Dye sensitized cells.

Research on organic solar cells was around 2000 on the production of Dye sensitized solar cells. Efficiencies of 2.5% have been reached with bulk hetero junction cells (PVPS, 2000). According to the annual report of ECN of 2000, the world was quite hesitative regarding organic solar cells. However the year 2000 represented a turning point because of the fast development that this technology was undergoing. ECN was very active with this technology and in cooperation with different other Dutch companies and research institutes like Philips, The Technical University of Eindhoven and the University of Groningen. They were working a new polymer cell based on $C_{60}$ molecules. These cells had efficiencies of 2.3% per square centimeter, which were significant results for that kind of cells. Dye sensitized production lines were further improved and the cells reached efficiencies of 4-5% on 4 $cm^2$. Further developments were focused on increasing the areas and improving the stability of the cells. Also, by adding electrolytes the cells showed less negative effects as a result of exposure to heat.

In 2001, Research on organic solar cells has been focusing on improving the efficiencies and increasing the areas of the cells while keeping the same or better efficiency. Polymer cell efficiencies of 8.2% on a 2 $cm^2$ have been reached. Improving the efficiencies was mainly by improving the stability and decreasing impurities. Also methods to increase the lifetime of the cells have been researched since these have a much lower lifetime than crystalline silicon (ECN annual report, 2001).

In 2008, ECN and Holst center started a research program to produce polymer solar cells with roll-to-roll processes. The research's aim is to look into the possibility of large scale production of polymer solar cells and how this will affect the efficiency of the cells (Brendel, 2008). Holst centre's value for the research on organic field comes from their expertise in the field of flexible electronics and OLEDs (Organic light emitting diode).

The University of Groningen (RUG) has also been working on organic solar cells for a long time. In 2007 research at the RUG led to the creation of one of the first organic "Tandem" cells. These cells contain multiple layers which can each absorb a different part of the sunlight spectrum and hence increase efficiency (RUG website). The polymer layers have to be separated in order for them not to mix up. The research arrived at creating a separation layer and made the material semi-transparent which makes it possible to use the cells in windows.

The technical universities of Delft and Eindhoven and the University of Utrecht are also active in the field of organic solar cells. Research at the TU Delft in 2008, for example, focused on increasing the number of released electron per photon and increasing the distance that an electron can achieve within the organic material (TU Delft website).

Meanwhile, ECN has dropped their activities on Dye sensitized solar cells (Kroon, 2011). ECN has been working on it for a while and it was not clear whether significant results were going to be achieved with this specific technology. This makes investors doubt whether they will ever make profits on their investments. Therefore, ECN continued only with polymer cells as this technology could profit from developments in organic electronics field (Kroon, 2011).

**Learning by doing and using**

The technology is still too immature to be produced in pilot lines or to be used in the Netherlands. ECN is working on production process together with Holst Centre. There have not been any Dutch companies that wanted to apply organic PV in their products so far (Kroon, 2011).

## CIS and CIGS solar cells

### Learning by searching

The Renewable Energy Program of 2001 (DEN, 2001) made it possible to start new researches on other technologies like CIS and organic solar cells, which did not get much attention by the NOZ-PV (PVPS, 2001). NOZ-PV and the Renewable Energy program will be discussed in Function 4 and 6 together with other investments.

Scheuten Solar started around the year 2000 with investigating the possibilities for thin film CIS in the Netherlands (PVPS, 2000). They expanded their research facility in Venlo by 20 researchers in 2003 (PVPS, 2003). The topic of the research was mainly CIS coated glass spheres that can be distributed over a substrate. TNO-TPD was part of the research project to look for fast deposition techniques for CIS. The company OTB looked into production technologies (AgentschapNL, 2011).

ECN is not very interested in CIGS and CIS because of the scarcity of indium (Bolt, 2011; Soppe, 2011). This scarcity would imply that the prices of indium will rise significantly once it is taken to large scale production and hence it will not be sustainable.

OTB and Smit Ovens are on the other hand very interested in CIGS. They produce manufacturing technologies for the cells. In a consortium called Cigself, they are combining their knowledge with other companies to make the production costs for CIGS cheaper. Smit Ovens' role will here be to improve the deposition and crystallization of the CIGS whereas OTB will work on the Transparant Oxide Layers. More on the Cigself consortium will be discussed in Function 3.

### Learning by doing

In 2005, Scheuten solar was still working on the improvement of their CIS production line on which they have been working for several years (PVPS, 2005). In 2006 they opened a pilot production line (Scheuten Solar website, 2011). Large scale production has not taken off yet.

### Learning by using

No data could be found on the use of CIS and CIGS in the Netherlands. The technology is still very much topic of research worldwide and the first company to have started commercial production was Würth Solar in 2006 as discussed in paragraph 3.4.

## CdTe solar cells

There is almost no research done on CdTe in the Netherlands. In 1997 there was no company or research institute that did research on this technology (ECN, 1997). Smit Ovens is the only company involved in this technology for the moment but is more involved in designing parts of the cell manufacturing machines. So improving these machines is the only research done on the field of CdTe.

## *Conclusions Function 2*

Most of the research was and is focused on *crystalline silicon* solar cells. This is mainly because these cells have the highest efficiency, are relatively stable and increasing the efficiency even more is possible. Besides, silicon is not scarce. The only negative side is the high production costs due to high energy costs and losses. Technologies like anti-reflective coatings and back contacts are some examples of techniques to improve the efficiencies.

*Amorphous silicon* was for a long time considered the best candidate for thin film solar cells. This is again because silicon is not scarce, it uses less silicon and the material does not have to be as pure as with crystalline silicon solar cells. A lot of actors are interested and are working on this technology given their high expectations. Important steps are being made that make the technology even cheaper and more reliable like improving the production speed and understanding effects that cause efficiency drops.

*CIS, CIGS and CdTe* are not very high on the research agendas in the Netherlands. This is because the materials used are scarce or toxic. The aim of solar cells is being sustainable and save the environment. This is not the case when we use these technologies according to ECN. However, CIS and CIGS are gaining more importance when it comes to R&D. CIS is being researched by Scheuten and there is consortium for R&D on CIGS. This consortium will be discussed in Function 3.

*Organic solar cells,* even though they are not commercially available yet is a very popular research subject in the Netherlands. This is mainly because it is going to be the cheapest solar cell once it can be produced on large scale and it is based on organic material which is not scarce. Many universities and research institutes have organic solar cells high on their agendas. Especially polymer cells are now topic of research because they have shown better results than the Dye sensitized cells and they can profit from knowledge generated in the field of organic electronics (Kroon, 2011).

It seems that the Netherlands are mainly doing fundamental and applied research. Companies like Nuon Helianthos and Scheuten are not very fast in taking their inventions to the market or setting up demonstration projects. This makes learning by doing difficult. Nuon Helianthos finished their pilot plant in 2009 and Scheuten finished their CIS pilot plant in 2006.

Crystalline silicon, amorphous silicon and organic solar cells get the most attention because these technologies are perhaps the best candidates when looking at the present (crystalline silicon), the short term (amorphous silicon) and the very long term (organic solar cells). Going back to Function 1, it still the question if Amorphous silicon is going to get as much attention in the future regarding the global shift towards CI(G)S and CdTe.

## 4.4 Function 3: Knowledge diffusion through networks

This paragraph is going to analyze to what extent the actors within the innovation system of each PV technology interact and collaborate to develop and diffuse PV technologies in the Netherlands. This is going to be done by first giving an overview on the seminars and workshops under the heading Formalized knowledge exchange. Then all collaborations that have taken place per technology are going to be discussed.

### *Formalized knowledge exchange*

Information can be exchanged between actors through seminars and workshops. The last couple of years there have been several of these formalized knowledge exchange events. However none of these seminars and workshops shows a preference for a certain technology. Mostly, they are organized to keep everybody up to date about the overall developments. Some of these events are described in this paragraph to give a glimpse on what the goals of the events are.

**ZON-dag seminar**

This seminar itself consists of two seminars that take place the same day once a year. The two seminars are “The Dutch Solar R&D seminar” and an event to show the possible applications for PV (ECN website; Joint solar panel, 2011). The seminars are meant to give actors an up to date view on the situation regarding all PV technologies and applications. There is not really a preference for one technology.

**The Solar Future**

This seminar is organized by the Dutch company Solarplaza and reunites actors from all over the world in the field of PV. This is to exchange knowledge and monitor the international trends and developments. This seminar again is not focused on one specific group of PV technologies but encompasses development in all technologies.

**Solar Technology**

These are several workshops organized in the end of 2010 and the beginning of 2011 to show the possibilities with of PV for Dutch companies. In a total of four days, each day was organized around a specific PV technology (c-Si, a-Si, CIGS&CdTe and organic PV). Each day, specialists would talk about the developments, market opportunities and value chains regarding the PV technologies.

**The Solar Academy**

In 2007, ECN initiated the establishment of the Solar Academy (ECN website). This was to provide operators, engineers and managers involved in the solar cell industry with the information they needed. The investments required for the academy are provided by industrial partners and especially NV Industrie bank LIOF in Maastricht and Solland Solar.  The LIOF bank was involved because they had the task to strengthen the economic structure of the province of Limburg. The trainings are not only for Dutch people from the industry but for people all over the world. In 2009 more than 100 people have been trained. The plan is also for the academy to function as R&D centre and many pilot production lines will be available for training and research purposes.

## *Collaborations*

Many collaborations have taken place over the years. Some of them were technology specific and some of them to give PV in general a push in the right direction. All the interviewed actors indicated that collaboration between them is very open. Most knowledge gathered by research is openly shared. Especially, the knowledge gathered by universities and institutes. In this paragraph, first the general collaborations will be elaborated on and then the collaboration per technology will be discussed.

### ***General collaborations***

*Joint solar programme*

In 2004, the joint solar programme was established by FOM, Shell Research and by the division of Chemical Sciences of NWO (the Netherlands Organization for Scientific Research). Since then, they organize meetings between people and companies who are active in the field of Photovoltaics twice a year. They also finance different fundamental researches that contribute to the improvement of solar cells. One of the important goals of the joint solar programme is to align the fundamental research to the business world. In 2008, Nuon joined this partnership with their subsidiary Nuon Helianthos (annual report JSP, 2010).

*Solliance*

Solliance is collaboration between ECN, TNO, Holst centre and TU Eindhoven. The collaboration started in 2010. They have a budget of about 70 mln euro and will work together on research on solar cell manufacturing machines. They are based in the so called ELAT region (Eindhoven, Leuven, and Aachen) and the aim is to put this region on the map when it comes to PV. The collaboration will work on establishing a ECN facility in the high tech campus in Eindhoven which will lead to many more activities on PV. Other aims of this collaboration is to create a platform and a strong network consisting of every actor involved in the PV industry and function as a promoter and advisory group for the government. Solliance is aiming to form a strong connection between laboratories and the industry to ease the way for thin film technologies to the market.

The technologies of focus for this collaboration are thin film technologies namely: thin-film silicon solar cells, CIGS, and organic solar cells (Solar magazine, 2010).

### ***Collaborations per technology***

#### Crystalline silicon solar cells

Around 1980 there was already a strong cooperation between the industry and Universities regarding crystalline silicon solar cells. Holec, of which Holecsol was a subsidiary, participated in research with several universities. Holec joined forces with the TU Eindhoven, which at the time was still called TH Eindhoven. (Verbong, 2001). Philips worked together with the University of Nijmegen on cheap production methods for Silicon. The researches were coordinated by the key financers FOM, SON (Stichting voor Scheikundig Onderzoek Nederland) and ZWO (The Netherlands Organization for Scientific Research, now NWO). The coordination made sure the different researches were aligned and each party was working on a different but important piece of the puzzle. Most of the research done around 1980 was on (crystalline) silicon.

During the mid-eighties, R&S (later Shell Solar) was working on crystalline silicon together with AMOLF, the research institute of FOM. AMOLF was working on improving the efficiencies of crystalline silicon solar cells and the improvements could immediately be applied in the R&S cell factories (Polman, 2004). The solar cell activities were later on transferred to ECN around 1991 (Weeber, 2011). Around 1994, R&S was working on improving the efficiency of solar cells to 16% together with ECN. The goal of the collaboration was to make the solar cells of R&S internationally competitive (EVN, 1994). ECN has the longest collaboration history in c-Si with the University of Utrecht and increasingly with the TU Delft (Weeber, 2011).

Many collaborations have taken place between industrial companies and universities. OTB Solar for example had a project for almost 5 years where they joined forces with TU Eindhoven to make technologies for large scale production of high efficiency multi-crystalline solar cells (Bosch, 2007).

ECN works closely together with Tempress, OTB Solar and Levitech. Also with TNO even though they are more specialized in thin film technologies but they have expertise in industrial processes which makes them valuable also for c-Si research (Weeber, 2011).

*Sunovation*

This collaboration on multi-crystalline silicon solar cells took place between 2000 and 2004 (Weeber, 2004). The participants of this collaboration were ECN, TNO, TU Eindhoven and Shell Solar. The goal was to reduce the costs of multi-crystalline solar cells and increase their efficiency. The technologies used to achieve the goals were developed by ECN, TNO and TU Eindhoven; and the tests on industrial scale were done at Shell Solar. The results of the collaboration were the invention of a silicon nitride deposition technology using Plasma Enhanced Chemical Vapor Deposition and the invention of the Pin-Up module described in Function 2. This led to an increase in efficiency to about 15% from 12%. Sunnovation was a follow-up on an earlier collaboration between ECN and Shell Solar called Promise, where the concept of Pin-up modules was explored and a prototype production machine for silicon nitride was invented. The Sunnovation project was subsidized by the Dutch EET programme (Economy, Ecology and Technology). This was an initiative of the ministries of Economic Affairs; Education, Culture and Sciences; and Spatial Planning and the Environment.

*Sunovation II*

As a follow-up on Sunovation, ECN started new collaborations with several other parties for Sunovation II. ECN joined forces with TNO, TTA (Tuinbouw Technisch Atelier) and Solland Solar to create a production line for Pin-Up modules. ECN was the coordinator and developed the module technology together with TNO. TTA designed the prototype for the module assembly equipment to automatically produce the modules. Solland Solar took over the role of Shell Solar who stopped their activities in the Netherlands (de Jong, 2008).

One of the other collaborations of ECN regarding crystalline silicon cells considers the Emitter Wrap Through technology EWT which is an improvement on back contact cells. ECN pioneered with this technology and is working on it with Solland Solar and Levitech which is a company specialized in semiconductor manufacturing machines.

## Amorphous silicon solar cells

One of the first collaborations on these cells was between the TU Delft and Holec as mentioned in Function 2. The aim was then to find ways to produce amorphous silicon.

### *The Helianthos project*

The Helianthos project started as collaboration between Akzo-Nobel, Shell, TNO, TU Einhoven, TU Delft and the University of Utrecht around 1997 (Roos, 2001; ter Beek, 2006). As described in Function 2, the aim of the project was to create a pilot line for a roll-to-roll process for amorphous silicon. Afterwards the responsibilities of Shell and Akzo-Nobel were taken over by Nuon.

A collaboration between TU Delft and TU Eindhoven resulted in the creation of a technology for faster deposition of amorphous silicon (van de Sande, 2002). This project was licensed to Akzo-nobel and Shell because it was interesting for the Helianthos project (TU Delta, 1999).

One of the latest collaborations of ECN regarding amorphous silicon and micro-crystalline silicon is with Tata Steel (Soppe, 2011). The collaboration was around the manufacture of a roll-to-roll process with steel substrates.

## CIS and CIGS

### *CIGSelf*

Cigself is a project that is aiming at research and development of new industrial level manufacturing processes for CIGS solar cells. It was initiated in 2010 (Solarmagazine, 2010). The collaboration is between Smit Ovens, Dutch Space, ECN, Holland Innovative, OTB Solar, Philips Applied Technologies, Scheuten Solar, TNO and TU Eindhoven. The goal is to raise the efficiency of cells to 12% when it is produced on an industrial scale. Therefore a strong collaboration between laboratories and industry is necessary. The collaboration's participants aim to establish a laboratory and finally a pilot project. With this pilot line each of the participants can test their new equipment once they invent it and see how it adds to the whole process. In the Netherlands nobody had knowledge on the whole production process. Instead everybody is specialized in a certain aspect (van der Gugten, 2011). What has been reached so far with the collaboration is that more than 90% of the equipment is ready to be applied. Smit Ovens for example almost finished manufacturing their equipment for the project (van der Gugten, 2011).

## Organic solar cells

Around 1998, the University of Groningen led a fundamental research project on polymer solar cells (Roggen, 1998). ECN, Philips and the TU Eindhoven were also participants in the project. The project was financed by the EET program which will be discussed more elaborately in Function 6. Around that same time, there were two clusters of universities (and institutes) working on organic solar cells. Cluster one consisted of TU Eindhoven, the University of Groningen and ECN and they were working on polymer cells. Cluster two consisted of TU Delft, University of Utrecht, University of Wageningen (WU) and ECN and they were working on an organic technology based on photosynthesis (not dye sensitized cells). The latter research was dropped because the results were disappointing (Kroon, 2011).

***Dutch Polymer Institute***

DPI is an institute that organizes projects related to polymer science. Organic PV is also part of the projects organized by the DPI. DPI collaborates with many institutes, companies and universities, like Philips, ECN, TNO, TU Delft, TU Eindhoven and many more. The aim of the collaborations is to acquire fundamental knowledge needed for developing third generation PV technologies (DPI annual report, 2009).

***ECN and Holst Centre 2008***

ECN and Holst centre signed an agreement in 2008 to work together on the development of organic solar cells (ecofys, 2008). The goal of this collaboration was to create Roll-to-Roll process technologies for large scale production of organic solar cells which makes them cheaper and more attractive for the industry. ECN has experience with organic solar cells while Holst centre has experience with roll-to-roll production technologies for organic polymer material. A combination of the expertise of both institutes is expected to lead to significant results. ECN and Holst centre are both research institutes and the aim of the researches they do together is to stimulate the industry with new solar cell technologies, but not to produce them themselves. So far there have not been companies that showed their interest in the final product in the Netherlands. There were however machine manufacturers that were interested in the manufacturing process (Kroon, 2011).

### *Conclusions Function 3*

When looking at Formalized knowledge exchange methods, usually when seminars or workshops are organized they deal with most of the PV technologies that are available. The seminars are mostly to keep every interested actor up to date on the newest developments and possibilities.

When looking at collaborations, one can see some differences between each technology. *Crystalline silicon* solar cells were at the very beginning researched at universities with help from subsidies and one company (Holec) that saw a potential in the product.  As there has always been only one producer of crystalline silicon cells, collaboration usually was between one company and a few research institutes and universities. ECN was involved in almost every collaboration considering crystalline silicon and the university that was mostly involved was TU Eindhoven. Thus, collaboration was between fixed key actors and in some exceptional cases other parties would join if their expertise is helpful.

For *amorphous silicon* solar cells, there is only one collaboration between universities and the industry which is the one of Nuon Helianthos. Other earlier collaborations have been more explorative too look into the possibilities of the technology.

CI(G)S research has not seen many collaborations so far. With the Cigself project this will perhaps change. Many actors active in PV are part of this project which shows their interest in the technology.

When it comes to *organic solar cells*, there is a lot of collaboration between different parties, especially research institutes and universities. This is because the technology is still very much in development phase and development can be done on different aspects. The technology can still benefit from input from different fields like roll-to-roll processing technologies, chemistry and organic electronics.

Collaborations on *CdTe* could not be found which again indicates the lack of interest in this technology in the Netherlands.

Most of the actors that were interviewed expressed that information is shared between the actors regarding all technologies. This is mostly because the technologies are still in development and keeping information secret will only hamper the innovation.

## 4.5 Function 4 Guidance of the search

This function describes the guidance of the search. In other words, how (and if) the Dutch government and companies showed interest in PV. Guidance is necessary for users and companies to form a positive outlook on the technologies' future and be willing to invest in them. In Table 4.1, the most important events are summarized and ordered by time of occurrence. This can provide a better overview between the happenings and the mindsets which either stimulated or hampered the use-of and investments in PV.

### *4.5.1 Guidance by the Government*

LSEO (Landelijke Stuurgroep Energieonderzoek) was part of the Ministry of Education and Science and had the task to look into the state of Energy production and use in the Netherlands. LSEO advised in 1975 to keep a wait-and-see position when it comes to PV. They argued that the added value of the Dutch research will have no influence compared to what is done on international scale (Verbong, 2001). Besides, LSEO argued that solar energy is not interesting enough for the Netherlands but is more suitable for warmer countries like Italy and Spain. They considered PV suitable for remote location and small scale applications. Regarding the fact that there were no areas in the Netherlands that were disconnected from the electricity grid, PV was not interesting. For coordination of the little amount of researches done, researchers turned to ZWO. ZWO is now called NWO (The Netherlands Organization for Scientific Research).

The energy whitepaper of 1979 (Energienota 1979), expressed clearly that PV was not going to be interesting enough for the Netherlands until the year 2000. If any solar energy would be applied on the short term it would be solar thermal power (Verbong, 2001). The first National Solar Energy Program (NOZ) was therefore only focused on solar thermal power. The NOZ was a stimulation program for solar energy executed by Novem on behalf of the Ministry of Economic affairs.

During the second NOZ (1982-1985), the program to stimulate solar power still expressed some hesitation considering PV. Research and projects on solar thermal power were getting far more subsidies than PV. However the ministry of economic affairs encouraged research on PV a little more only to keep up with international progresses on PV. The ministry was still expressing doubts and hesitation regarding PV.

The third NOZ (1986-1990) came with a special program for PV and was called NOZ-PV. This time about one third of the budget of the NOZ program went to PV. However, there was still a lot of pessimism regarding the technology. The ministry of economic affairs wanted to increase the attention to PV not because of the short term benefits for the Netherlands, but because they wanted to keep up with progresses in other countries and because there could be a beneficial market in developing countries (Verbong, 2001).

Research done in order of the Ministry of Housing, Spatial planning and the Environment around 1987 pointed out that polycrystalline silicon solar cells, amorphous solar cells and III-V solar cells are probably going to be used most in the future. This is due to the already gained experience with the material and low price possibilities (amorphous silicon cells). However, specialists still thought it was too early to point out one technology and put all the focus on it. The division of the subsidy money of NOZ-PV also did not really point out a favorite technology.

Problems with the environment around 1987 led to an increase in attention to renewable energy by the Ministry of Economic Affairs. The minister however saw more possibilities for wind energy instead of PV. His argument was that there was more wind than sun in the Netherlands. Despite the doubts, the government implemented the SES subsidy program where maximally 40% of the price of autonomous PV systems could be refunded by the government (Negro, 2008). The SES subsidy was however not specially for PV but for all renewable energy projects.

Turkenburg, a specialist on the field of PV argued in a report he published in 1989 that PV underwent a tremendous price drop from around 100 $/Wp in 1970 to about 5 $/Wp in 1989 thanks to the fast technology developments. He argued therefore that the price drop can be even more significant in the future especially for amorphous silicon that could reach about 0.3 $/Wp when it is massively produced. Thanks to reports like those of Turkenburg, the Minister of Economic Affairs of 1990 expressed in the 1990 Energy whitepaper that PV should get more attention as it could be one the most important energy source by the year 2010. The goal was set to replace 2 PJ of fossil fuels by PV which is equal to 240 MWp of PV systems (Verbong, 2001; Negro, 2008). Furthermore, the success of PV projects in the developing countries proved the economic viability of PV in the Netherlands in the future.

Shell published around the beginning of the nineties a report of a scenario analysis. PV was considered a very important energy source according to this scenario analysis. Regarding the fact that Shell was at the time not very involved in PV and because their core business were fossil fuels, key actors from the ministries also started to see the viability of PV technologies. Other positive impulses that led to more acceptance of PV came from successful projects in the Netherlands where PV proved to save a lot of energy especially when connected to the grid. This way the excess energy can be fed back into the grid instead of using it only to charge batteries. Also, the other renewable energy sources like wind energy and bio fuel were not as successful as was initially expected.

Around 1994, the government decided to end the SES subsidy program gradually. Instead, many other financial stimulation incentives were implemented, mostly fiscal. The third Energy Whitepaper of 1995 showed the goals of the Ministry of Economic Affairs to reach a production of 10% of sustainable energy by 2020. PV should by then replace 10 PJ of the fossil fuels which represented at that time around 0.5% of the energy use. To reach these goals the price of PV systems should be ten times lower than what they were, from 1.5 guilders/Kwh to 0.15 guilders/KWh. The instruments to reach these goals were fiscal benefits, subsidies, improvement of (building) regulations and subsidies for R&D (EVN, 1997).

The NOZ-PV program of 1997-2000 focused next to R&D a lot on market stimulation (EVN, 1997). Where NOZ-PV used to stimulate cell research, they also realized the importance of other related technologies like inverters and technologies to integrate the modules on i.e. rooftops. Part of the NOZ-PV 1997-2000 was the PV-Covenant which is an agreement between the government and several parties from the PV market.

In 2001, the Ministry of economic affairs again expressed their doubts about the role that PV can play in renewable energy production. Their expectations were again more in favor of wind and biomass energy (PVPS, 2001). The way of granting subsidies also caused a lot of confusion where the Energy Premium Regulation (EPR) was only granted to house owners and housing corporations who paid an Ecotax. This subsidy could be raised by 25% after doing an Energy Performance Assesment (EPA). The EPR made many house owners willing to buy small PV systems for their homes (PVPS, 2002). On the other hand, project developers who could have the capability to install large scale PV systems on large buildings could not apply for EPR which led to the loss of a lot of potential applications for PV.

In 2002, the responsibilities for PV were turned to the Ministry of Housing. One of the benefits of this change is that construction permits were no more needed for small PV systems (PVPS, 2002). With the drop of construction permits and an increase in the EPR subsidy that could reach 5.35 euro/Wp, the demand for small PV systems showed a staggering increase (PVPS, 2003). This is a logical reaction of the market considering that the price of a system was not much higher than the refund as can be noted in Figure 1.5 of paragraph 1.4.2. The demand was so high that the government announced to end the possibility to apply for a EPR subsidy by October 2003. The utility companies which also provided subsidies were as well running out of subsidies for their customers. This led to even more demand for small PV systems as everybody wanted to apply for a subsidy before everything would end. In 2003 the preferences for the governmentally financed Energy R&D program (EOS) were defined (PVPS, 2003). It showed a great importance of PV in the future and especially polycrystalline and non-organic PV technologies were expected to play a big role.

In 2004, the EPR subsidy was ended next to the subsidies provided by the utility companies. This led to a large downfall of the demand for PV systems in the Netherlands. The amount of additional PV systems installed dropped from 19.8 MW in 2003 to 3.2 MW in 2004. Many companies involved in PV ended their operations and others turned to the German market (PVPS, 2004). The EAP tax refund was not remitted to many customers of a company called Beldezon. This company went to court against the Tax and customs Administration and won the lawsuit which resulted in a refund to their customers after all (EVN, 2004). The year 2005 did not show any amelioration compared to 2004. There were no subsidies except for R&D (PVPS, 2005). There was also a very small feed-inn tariff of

0.097 euro per kWh which also needed all kinds of certifications which made PV unattractive for consumers.

In 2006, again, there were not many initiatives by the government to encourage the use of PV. The feed-inn tariff was still 0.097 euro/KWh. The government however also obliged utilities to buy electricity back from their customers for 0.20 euro/kWh up to 3000 KWh. Enterprises could get a tax reduction when using renewable energy. This was the so called Energy Investment Rebate. The little amounts of PV systems installed were mainly local initiatives. For example, the province of North Holland was granting 3 Euros per Watt peak installed in the region (PVPS, 2006).

In 2007, the government set some goals that they want to achieve by the year 2020. The goals included a 30% decrease in CO2 emission compared to the year 1990 and a contribution of renewable energy of 20% of the energy needs. To achieve the goals, the government introduced the Stimulation Sustainable Energy Production programme (SDE) which was launched in 2008. The SDE provided small scale PV systems with a subsidy of 0.33 euro/kWh on top of the fossil electricity price. The SDE was planned for 15 years and the subsidies would depend on the market prices.

In 2009, the SDE was the main subsidy for PV owners. There was therefore a little increase in the amount of PV systems installed (PVPS, 2009). The government had more confidence in technologies like wind energy but saw PV as a main energy provider on the mid- and long-term. Again initiatives to install PV depended on the provinces and not only on the government. In 2010, the goals of the new government were less ambitious regarding renewable energy than before. Renewable energy was now targeted at 14% of the total energy use. The SDE subsidy was cancelled until a new SDE is to be expected in 2011. This one is only going to be applied for systems above 15 kWp and the maximum remuneration is 0.15 euro/kWh (PVPS, 2010).

| Period | 1975-1985 | 1986-1990 | 1990-1997 | 1997-2001 | 2001- 2004 | 2004-2007 | 2007-2010 |
|---|---|---|---|---|---|---|---|
| The government's attitude towards PV | - PV was not considered to be suitable for the Netherlands<br><br>- The government expressed doubts and hesitation regarding PV<br><br>- Solar thermal received more attention | - Still not convinced of the usefulness of PV in the Netherlands<br><br>- Stimulation of research just to keep up with international developments and exploit markets in developing countries<br><br>- Renewable energy gained importance but wind energy was considered a better option instead of PV | - PV became one of the most important renewable energy sources in the Netherlands<br><br>- Goal of 2 Peta Joule of PV energy by 2010 (1990)<br><br>- 10 Peta Joule of PV energy by 2020 (1995) | - PV research needed to be stimulated to attain the desired price decrease to reach the goal of 10 PJ of PV energy by 2020 | - The government again expressed its doubts when it comes to PV and was more in favor of wind and biomass<br><br>- polycrystalline cells and other non-organic cells were expected to have most potential | - Renewable energy production was encouraged with small subsidies<br><br>- No special attention for PV | - Goal was set to decrease CO2 emissions by 30% by 2020<br><br>- 20% of renewable energy by 2020.<br><br>- Wind energy was considered to have a better chance but PV was expected to play role on the longer term (2009)<br><br>- Goals for renewable energy capacity was set to less ambitious goals (14%) by the new government in 2010. |
| Important happenings | - LSEO gave a negative advice considering PV (1975)<br><br>- NWO coordinated the little research done in the Netherlands<br><br>- Energie white paper (1979) argued that PV is not interesting fir the Netherlands<br><br>- NOZ (1982-1985) had a preference for solar thermal, not for PV | - First NOZ-PV which gave special attention to do research on PV<br><br>- Polycrystalline silicon, amorphous silicon and III-V compounds were considered important candidates for PV power applications (1987).<br><br>- 40% of an investment in renewable energy could be refunded including PV with the SES subsidy (1987) | - Projects with PV in development countries proved the viability of the technology<br><br>- Shell showed interest in PV and herewith PV gained more attention from the government<br><br>- SES subsidy was ended but other mostly fiscal aids were initiated | - NOZ-PV 1997-2000 to stimulate cell research and research on Balance of the System<br><br>- PV-covenant as part of NOZ-PV to stimulate the market and improve the connection with the government | - EPR subsidy for home owners and housing corporations +25% after positive EPA assessment<br><br>- Subsidies from utilities (2002)<br><br>- Ministry of housing took over the PV responsibilities (2002)<br><br>- Staggering increase in demand for PV | - EPR and utility subsidies ended in 2004<br><br>- Small feed-inn tariff of 0.097 euro/kWh (2006)<br><br>- Tax reduction for renewable energy generation (2006)<br><br>- More local initiatives from municipalities instead of the government | - Launch of the SDE subsidy in 2008, first for small scale PV systems<br><br>- SDE was ended in 2010 and replaced by a new one only for big PV systems of 15 kWp |

**Table 4.1: Most important developments that had influence on guidance of the search**

### 4.5.2 Guidance by companies

In 1989, the government published a National Environment Plan (Verbong, 2001; Negro, 2008). This plan that aimed to stimulate sustainability, next to the increasing awareness of dependency on fossil fuels, encouraged energy distribution companies to publish their first Environmental Action Plan (MAP-1). The companies herewith dedicated themselves to contribute significantly to sustainability and environmental friendly energy supply. The publicity campaigns of companies that formed the MAP encouraged also sustainable energy use among customers. This led to more acceptance of i.e. solar panels on rooftops (EnergieNed, 2000).

Part of the NOZ-PV 1997-2000 was the PV-covenant. This was an agreement between the government and different parties from the market and R&D institutions to work together on achieving 7.7 MW of grid connected PV in the built environment by the year 2000. The covenant was signed by 15 parties which were ECN, R&S (Shell Solar), the Ministry of Economic Affairs, several Energy Utilities and distribution companies and their branch organizations (EnergieNed), project developers from i.e. the building industry and Novem. As a result of the covenant the government and actors in the market could align their goals and the collaboration led to the initiation of several projects. The goal of 7.7 MW has therefore been achieved (IEA, 2000).

In 2002, to show the importance of PV in green energy supply; and to compete into the liberalized energy market companies like Nuon and Eneco decided to grant subsidies of 1 euro/Wp for consumers that become their customers and generate energy from PV. The utilities expressed their devotion to green energy and PV by setting large projects like that of the biggest PV rooftop at the Floriade building (PVPS, 2002). All this was to encourage their customers to produce and use green energy and PV. NGO's like Greenpeace and WWF granted certificates to buildings that use solar power (PV but also solar thermal).

### 4.5.3 Technological expectations

During the eighties and the nineties crystalline silicon has been considered the short term candidate and amorphous silicon would take over on the long term (Verbong, 2001). With the upcoming of other PV technologies the view changed a little. C-Si panels have always had the greatest market share, this was expected to be taken over by thin film technologies (CIGS, CdTe, a-Si…) and then organic solar cells would take over because they are much cheaper. This view turned out not to be entirely true (Kroon, 2011). The technologies are now mostly expected to co-exist. Figure 4.5.1 shows that crystalline silicon cells are expected to maintain the highest efficiency. Therefore, unless thin film technologies become much cheaper, c-Si will still have the highest market share especially in the Netherlands where there is not much space, a lower efficiency means more space is needed to attain a certain power capacity. The technology that is getting increasingly more attention in the Netherlands and in the world is CIGS this is because of its possibility to be printed and the process does not need to be done in vacuum (van der Vleuten, 2011; Roadmap zon op Nederland, 2011). This technology has also the highest efficiency among the thin film technologies. It is still unclear which technology is going to have the most success. CIGS for example might reach high efficiencies and low production costs possibilities, but the materials used to make it are scarce which can drive up the prices and make it difficult for this technology to compete on the long run.

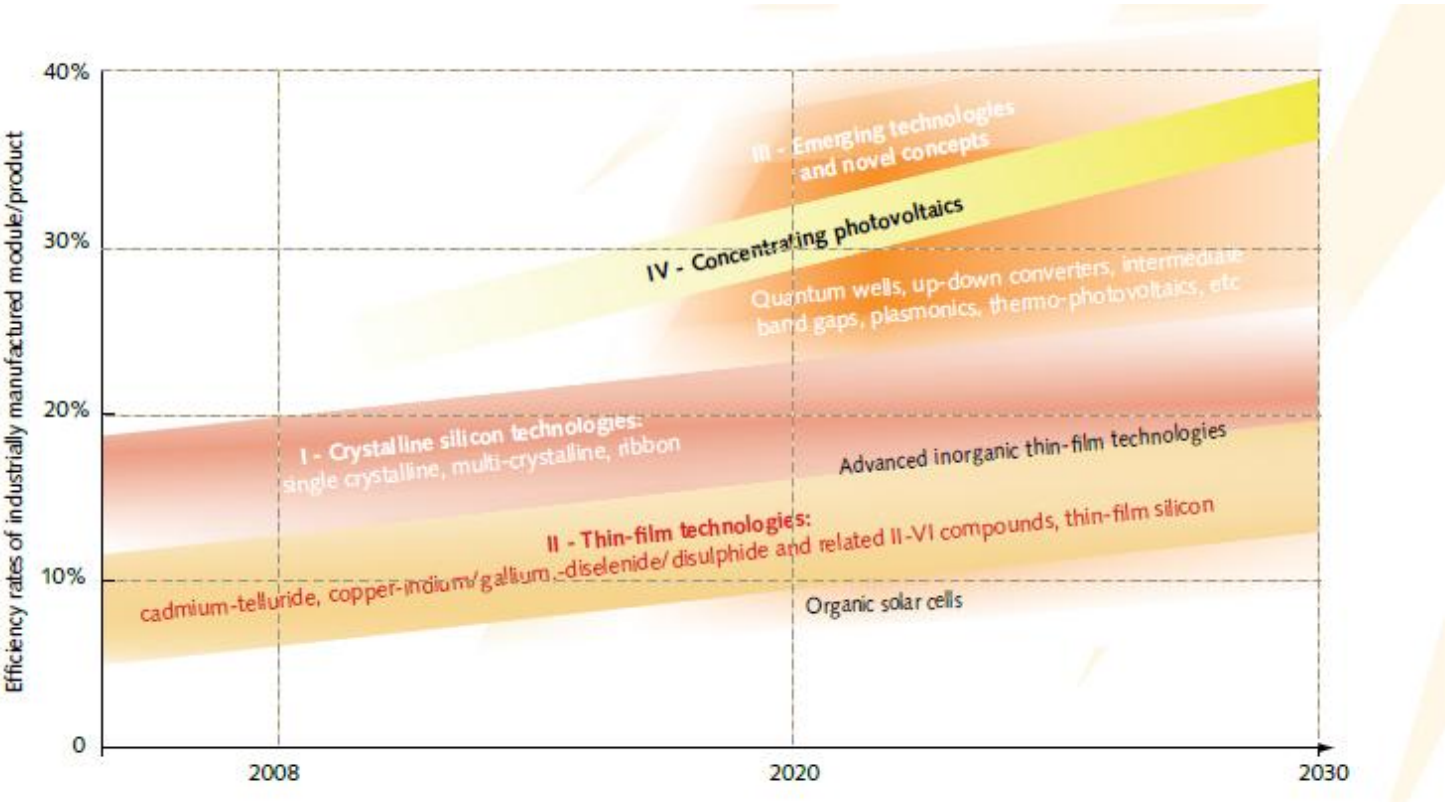


**Figure 4.5.1: Current and expected efficiency per technology (Roadmap zon op Nederland, 2011)**

## Conclusions Function 4

Until 1986, the government was totally not interested in PV and its opportunities. The financial aid for PV R&D was mainly to keep up with foreign progress. It was not seen as a possible candidate for large scale energy production. In 1986, a bigger share of the NOZ was granted to PV research, not because of the short term energy benefits for the Netherlands but to keep up with other countries and because developing countries could be interested in it. These countries usually have remote areas that are not connected to the grid and then PV could be lucrative.

Assessments done in order of the government usually showed negative results regarding PV. If some assessments saw some opportunities, it was for crystalline silicon solar cells and amorphous silicon solar cells. This was mainly because there was experience with the material and amorphous silicon could be produced at a low price.

Around 1994, the government started to subsidize PV. The subsidies were not specifically for PV but for renewable energy systems in general. Many subsidies followed and many were cancelled. This led to a lot of confusion and hesitation in the market. The government was clearly not giving a trustworthy image encouraging investing in the technology.

Cooperation between the government and companies involved in PV had positive effect on the market as the goal of 7.7 Megawatt that was set by the involved parties was achieved. Apparently customers responded to this collaboration in a positive way.

The feed in tariff set by the SDE subsidy which led to an increase. But, because the amount of subsidy reserved for feed in tariffs was limited, the subsidy was quickly halted and will be replaced by another subsidy.

The guidance was not in favor of a particular PV technology. However, the technologies with which there is the most experience are usually mentioned. These were especially crystalline silicon solar cells and amorphous silicon solar cells.

It has for a long time been thought that thin film technologies will take over c-Si modules, and that organic PV will take over thin film PV. However, this is not the case anymore regarding the last developments and expected efficiencies. They are probably expected to coexist.

## 4.6 Function 5 Market formation

This paragraph will describe the market for PV technologies. The market has seen several changes and regulations in order to protect this market. These developments will be explained by first elaborating more on the transition from stand alone (autonomous) PV systems to grid-connected systems in paragraph 4.6.1. Then, in paragraph 4.6.2, the way the market has been stimulated and protected by subsidies and regulations will be discussed; and how that has affected the demand. Paragraph 4.6.3 will elaborate on the export of PV, followed by paragraph 4.6.4 and 4.6.5 which will respectively discuss Building Integrated PV and (possible) niche markets.

### *4.6.1 From stand alone PV systems to grid connected systems*

Before 1995, PV systems were used as standalone systems for buoys, yachts, illumination of remote areas, caravans, garden houses and drinking troughs for cattle (CBS, 2003; Verbong, 2001). For many of these applications standalone PV systems were cheaper than other energy options (EVN, 1997). However, as can be noted in Figure 4.6.1, the amount of applications was not so high that PV could make a significant difference in the energy production.

Around 1995 a new application got increasing attention. This was the grid connected PV system (CBS,2003; Verbong, 2001). Actually the first demonstration with grid connected PV was done in 1991 when 10 houses in Heerhugowaard were equipped with grid-connected PV systems (van Mierlo, 2002). The first following projects were around 1995 and 1996 in Amersfoort, Apeldoorn and Amsterdam and relied heavily on subsidies (van Mierlo, 2002). The advantage of a grid-connected system is that it can feed the excess energy back to the grid. This increases the efficiency of the system. In standalone systems, when the energy is not used and battery is fully charged, the excess energy has no use and hence the system loses efficiency. With grid connected systems the excess energy could be used by somebody else. Figure 4.6.1 shows the rapid growth of grid connected PV systems compared to stand alone systems. Because excess energy is fed back into the grid, the energy bill is lower; and because the subsidies changed from remuneration on the system price to feed in tariffs (Function 4), apparently stand alone systems became less attractive than grid connected systems. This shows clearly in Figure 4.6.1 as between 2000 and 2009 the capacity of standalone (autonomous) systems hardly changed.

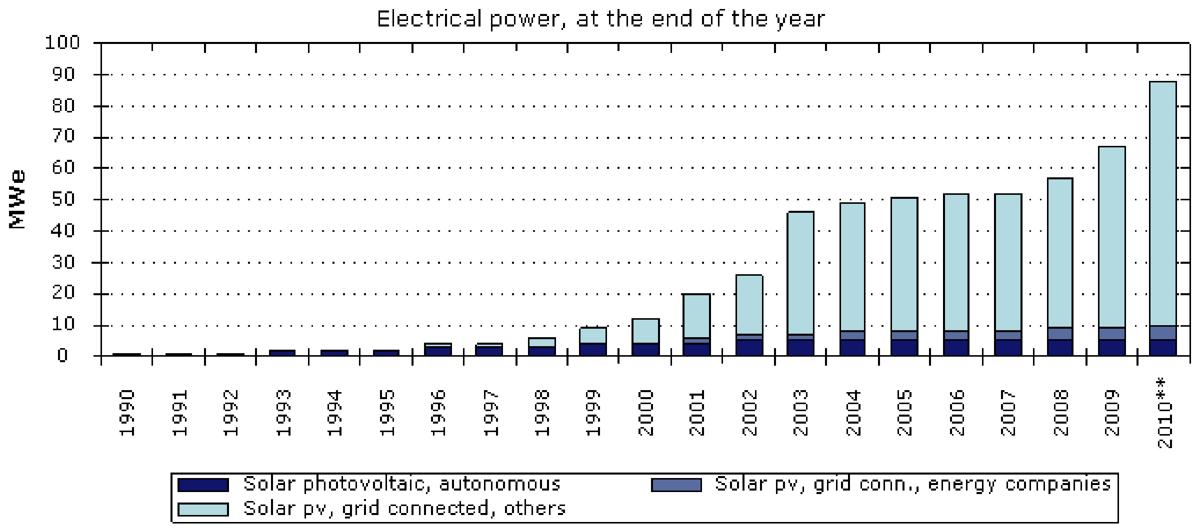


**Figure 4.6.1: Stand alone and grid connected PV capacity 1990-2010 (CBS Statistics Netherlands, 2011)**

### 4.6.2 Stimulation of the market

***Effect of subsidies***

Function 6 describes the subsidies that were granted to stimulate development and diffusion of PV in the Netherlands. That function describes the SDE and the MEP subsidy. These were also mentioned in Function 4. In order to apply for these subsidies, renewable energy producers have to be subscribed to a company called CertiQ (CertiQ, 2011). CertiQ is a subsidiary of Tennet, a Dutch grid operator. CertiQ provides its subscribers with certificates that prove their owning of renewable energy generation systems. This way, utilities can prove that they are active in green energy production and they can trade these certificates. To assess the effect of subsidies, the increase in PV capacity of CertiQ members has to be compared with data from Statistics Netherlands CBS which encompasses the total capacity (subsidized and non-subsidized). This is what this paragraph is going to analyze.

18 Megawatt has been realized with the SDE subisidy which started in 2008 (Agentschap NL year review, 2010). The report of AgentschapNL (Agentschap NL year review, 2010) was written in 2011 which means that it also includes all systems installed in 2010. So between 2008 and the end of 2010, 18 MW has been installed with (or as a result of) subsidies. Looking at Figure 4.6.2 and the numbers from Table A.4 in appendix A. It shows that 36 Megawatt has been installed in this period according to Statistics Netherlands (CBS). This means that about 50% of the newly added PV systems have been installed without SDE subsidy.

With the MEP subsidy, 13 Megawatt of systems have been installed by 2010 producing 4,570 MWh (Agentschap NL year review, 2010). The year review of 2009 only shows the production which is 3,500 MWh. With a simple approximate calculation it can be computed that the total capacity installed by the end of 2009 was about 10 Megawatt of PV systems ((3500/4570)*(13MW)). The total amount of SDE and MEP subsidized systems was 4.422 MWh in 2009 which means that SDE subsidized systems represented around 21% of the production by the end of 2009. For the capacity installed before 2009, the statistics year review reports of CertiQ of 2008 can be consulted (CertiQ year review, 2008). This review shows that in 2008, 3.783 MWh has been produced with subscribed PV systems, including SDE. Considering this fact in addition that SDE just started in 2008 and that SDE subsidized capacity represented 21% in 2009, it can be concluded that the greater majority were systems subsidized by MEP. Therefore in 2008, the installed capacity of MEP subsidized systems was already around 10 MW.

All the previous calculations show that the installation of SDE subsidized systems started when the MEP subsidized systems only had 4 MW left to install. 3 MW of these MEP subsidized systems had been installed between 2008 and 2010. Going back to the data from CBS that says that 36 MW has been installed between 2008 and 2010, it can be concluded that 15 Megawatt [(36MW)-(18 MW SDE)-(3 MW MEP)] has been installed without any subsidies from SDE or MEP. That is equal to 42% of the total additionally installed capacity between 2008 and 2010.

The CertiQ statistic year review of 2011 shows that the certified (and subsidized) production increased by 7 to 8 MW in 2010. Comparing this again to the CBS data in table A.4 which shows an increase in 2010 by 21 MW, reveals that 62% of the additional capacity was installed without SDE and MEP subsidy.

CBS mentions several reason for the difference between the CBS data and the data from CertiQ and hence the large number of unsubscribed systems (CBS,2009): Older systems installed before SDE and MEP (2003) that came into force after 2003 cannot not receive subsidies and are therefore not subscribed; CBS measures the delivery from distributers to system installers and end users, which means that some systems could be installed and registered a long time after the procurement, or installers install the systems abroad; registration at CertiQ takes time so systems could be installed before they are officially registered; municipalities provide subsidies in the form of a system costs refund and these systems do not need to be registered at CertiQ; and some systems could just be installed without any subsidy.

A strong increase can be noticed between 2001 and 2003 which represented the beginning and the end of the EPR subsidy. The EPR was cancelled by the end of 2003 because it was sensitive to fraud (Tweede Kamer der Staten-Generaal, 2005). Some systems which received the subsidy were not installed and it is not easy to monitor if the system is actually active when installed.

The owners of EPR subsidized systems were not registered at CertiQ (at least for a very large part). Judiging by the number of users found in the statistic year review of 2003 of CertiQ (CertiQ, 2011), which is 229 subscriptions, the subscribed capacity installed was about 1 MW. Whereas the capacity installed between 2001 and 2003 amounted 34 MW according to the CBS Data.

The systems installed before 2001 were mostly autonomous which were already cost effective in some applications as mentioned at the beginning of this paragraph. The grid connected systems were mostly heavily subsidized demonstration projects (van Mierlo, 2002).

To conclude, users of PV systems show strong responses to subsidies. The periods where subsidies where granted show a clear rise in installed capacity. The last couple of years almost half of the installed capacity was installed without MEP and SDE subsidy, but still this does not mean that subsidies are not needed anymore because there are still ways to obtain a partial costs refund from municipalities for example. Therefore the exact amount of systems that are installed subsidy-free is unclear. Further information on the installed capacity could not be obtained from Statistics Netherlands CBS.

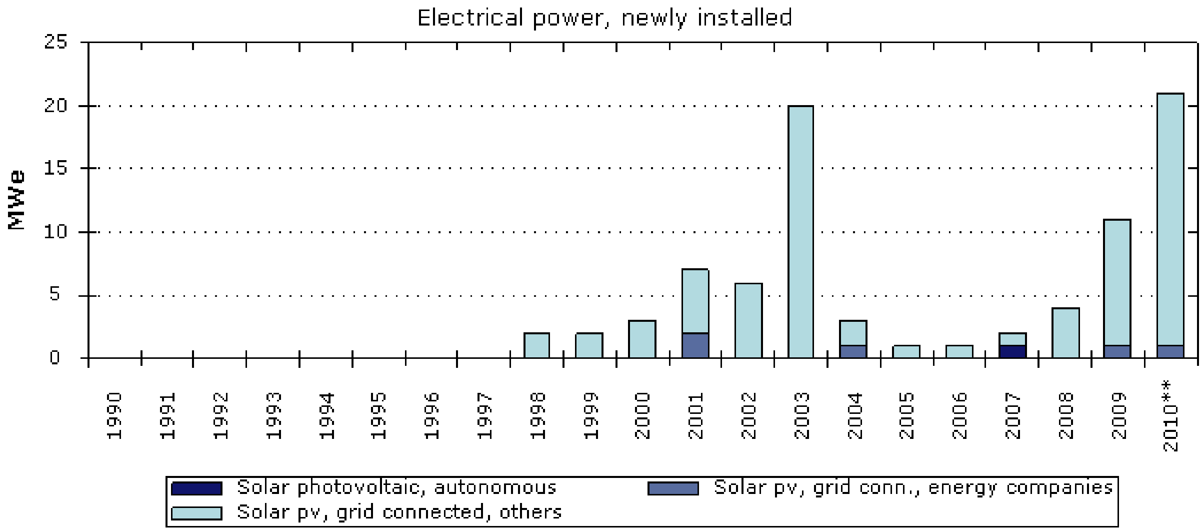


**Figure 4.6.2: Additional PV power installed for the years 1990-2010 CBS Statistics Netherlands, 2011)**

***Protection of sustainable energy producers***

The electricity law of 1998 determined that producers of sustainable electricity could set off the produced electricity in KWh against what they have used from the net. Electricity utilities have to subtract the energy produced by a customer from what the latter used from the net. This, with a maximum of 3000 KWh; and under the condition that the customer produces less energy than used from the utility. For example: If somebody produces 4000 KWh per year with PV panels and uses 8000 KWh from the net, only 5000 KWh have to be paid to the utility (8000-3000). The customer is compensated for 4000 KWh of solar energy but for the 3000 KWh defined by the law. Some utilities increased the amount of energy that can be compensated to 5000 KWh to attract more customers. This way the customer of the last example would have to pay only for 4000 KWh (8000-4000). At the moment it has been defined by law that the utilities have to recompense 5000 KWh, and some of them recompense more to attract customers (Veenstra, 2011; Wouterlood, 2011).

## *4.6.3 Import and Export of PV products*

**The export**

Around 1986, about 80% of all the cells, panels and other technologies related to PV were made for export. Solar Home Systems was an attractive market for solar cell and panel manufacturers in the Netherlands like R&S Renewable Energy (later Shell Solar). Projects in Indonesia financed by the

Dutch government provided R&S Renewable energy with the opportunity to sell their panels for an attractive price and prove that PV can make a difference especially in sunny developing countries.

Between 2004 and 2009, the export of PV panels has risen from 9.8 Megawatt to 127.4 Megawatt (Figure 4.6.3). This is remarkable comparing these export figures to the total amount of PV panels installed in the Netherlands which amounts 69 Megawatt in 2009 (See Figure 4.6.1); and the incrementally installed capacity installed between 2008 and 2009 was 10.9 Megawatt (Statistics Netherlands CBS, 2011). So the locally installed PV capacity in the Netherlands was 8% of the exported capacity in 2009. Around 2009, 90% of the turnover of Dutch PV companies was made abroad (CBS, 2009). This shows that the Dutch companies involved in PV rely heavily on the markets outside the Netherlands. Interviews pointed out that Germany has always been a very attractive export market but also France, Spain, Italy and Belgium have important customers.


**Figure 4.6.3: Export of PV solar panels from the Netherlands (CBS Statistics Netherlands, 2011)**

**The import**

In paragraph 4.2, Function 1 described that Shell Solar was roughly the only cell and panel manufacturer in the Netherlands until the end of 1996. Afterwards, many foreign companies started to enter the Dutch market. As can be seen in Table A.1 in Appendix A, the import between 2004 and 2006 exceeded the export. The import data is only available for this period (2004-2006). Afterwards the data became secret. CBS could not explain why this information became secret. As possible explanation they argued that companies that gave access to their data were not cooperative anymore.

Analyzing the data from table A.1 and A.4 shows that the high imports between 2004 and 2006 were not installed in the Netherlands. For example in 2006 the imported capacity of panels increased to 25,052 KWp (25 MWp), whereas the additionally installed capacity in the Netherlands was 2 MWp. The export amounted 22,148 KWp. In addition, the only Dutch cell and panel producers were respectively Solland Solar and Ubbink Solar Modules, with a production of 18MW for Solland Solar and 2.6 MW for Ubbink Solar Modules in 2006. The data of CBS considers only PV panels. Therefore if only Ubbink solar Modules is considered, The Netherlands produced 2.6 MW. This means that the panels that were imported were almost all exported again. This could be done by installers who installed the panels abroad. Until 2009, Ubbink Solar Modules got their cells from Solland Solar (Pruissen, 2011). This is not the case anymore. Their cells are now mostly imported from Asia as these are cheaper.

### 4.6.4 Building integrated PV (BIPV)

Building integrated PV systems are PV systems that take over the functions of a component of a building and at the same time provide PV energy (Agentschap NL, 2010). PV panels could be integrated as roofing tiles (Figure 4.6.4) or in glass in windows (Figure 4.6.5).

**Figure 4.6.4: PV panel as roofing tile (Agentschap NL, 2010)**

**Figure 4.6.5: PV panels integrated in glass (Agentschap NL, 2010)**

Crystalline silicon cells as well as thin film PV technologies can be used for building integrated solutions. The advantage of thin film technologies on substrates is that they are more flexible and they can cover many differently shaped areas. Organic PV could be attractive for BIPV because these cells can be produced in different colors unlike the current PV cells that are on the market (Kroon, 2011). However the technology is still too expensive and unstable.

### 4.6.5 Niche markets

The solar cell technologies that are available on the market at the moment can be distinguished on price/performance ratio, flexibility and color. When the modules are not flexible, the application is practically the same and only the price/performance ratio is of importance and perhaps the color. Amorphous silicon i.e. can be produced on glass and on flexible substrates (Stigter, 2011). This makes it attractive to apply on constructions that cannot take the heavy weight of panels and its mounting devices (Stigter, 2011). There might also be some BIPV applications for which thin film technologies on substrates are more suitable than c-Si technologies based on wafers.

System components needed for the functioning of a PV system other than the modules are summed together with other expenses like installation labor under “Balance of the System” or BOS. Panels using low efficiency PV technologies need a larger area to achieve the same amount of power produced by a panel with a higher efficiency. When the area needed for the panels is larger, more space is needed which comes with a cost, more (longer) wiring is needed and more construction material is needed to fix the panels to its position. This is the main reason why thin film solar cells have difficulties competing with crystalline silicon solar cells which have higher efficiencies. An example is given in Figure 4.6.6; here, crystalline silicon solar panels are compared to CdTe panels in the United States. Looking at the price for utilities (fixed-axis), it is clear that the total price of the system is higher for CdTe even though the price of the module is much lower. This is mainly due to installation material and installation labor.

Whether the BOS costs are lower when thin film silicon technologies on substrates are used is questionable. Perhaps it is a matter of perspective, depending on the application, as the specialists interviewed had some differences of opinion regarding this detail (Zeman, 2011; Soppe, 2011; Stigter, 2011). When installing a PV system on a light (weak) structure, strengthening the whole construction to support PV panels can increase the BOS costs significantly while this is not the case when flexible PV modules are used.

Organic PV is still too expensive to be competitive for power applications. They are expected to be applied in consumer electronics first. There are already companies abroad applying the technology in for example handbags to charge mobile phones but in the Netherlands that is still not the case (Kroon, 2011).

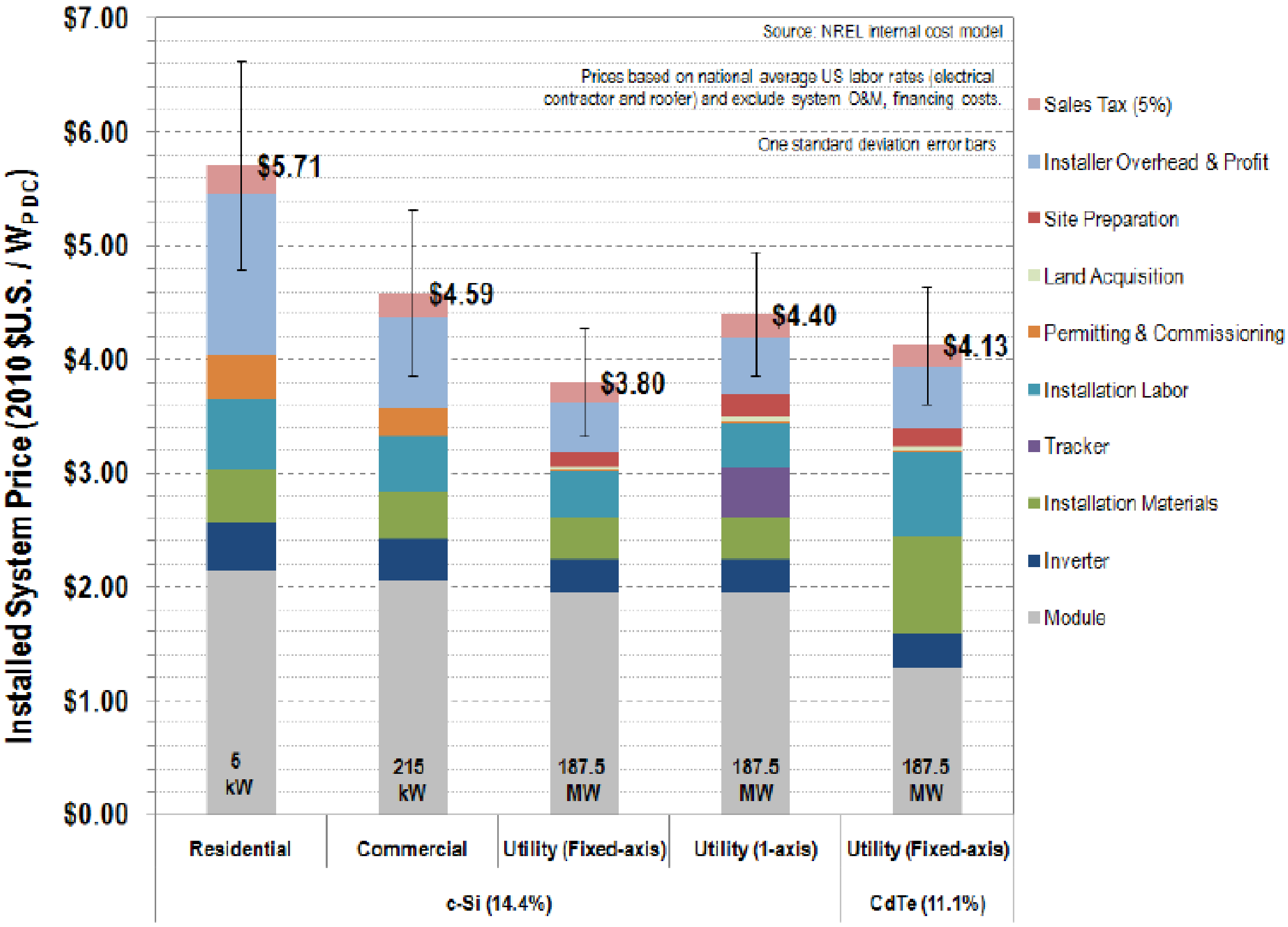


**Figure 4.6.6: price comparison between c-Si PV system and a CdTe system (NREL, 2011)**

### 4.6.6 Conclusions Function 5

Almost all installed capacity in the Netherlands has been realized through the help of subsidies. Increases in capacity are noticed immediately when subsidies are available. This was mainly between 2001 and 2003, when the EPR subsidy was available; and 2008 until now with the SDE subsidy. 2010 also shows a large increase in systems that are not subsidized by SDE but there is not enough information available to conclude that people are now willing to buy PV systems without subsidies.

Dutch PV panels and cell manufacturers have always relied on export. The home market is too small and unstable as can be seen in Figure 4.6.2. Apparently this is especially due to the unstable subsidy programs also mentioned in Function 4.

At the moment thin film PV technologies can hardly compete with c-Si cells when it comes to non-flexible panels. Their efficiency is lower which makes their BOS costs higher. The efficiencies of thin film PV technologies will stay lower for a long time. Therefore thin film technologies only make a chance in flexible form. This way they are easier to use for BIPV applications and on weak constructions that cannot take the heavy c-Si panels. Organic PV are still too expensive and unstable to compete with either c-Si or thin film PV when it comes to power applications. They do have the advantage that they can be made in different colors unlike other PV technologies which makes them attractive for some BIPV applications in the future but they are not used yet in that form. Their first application will be consumer markets but up till now there is no Dutch company that makes these applications.

## 4.7 Function 6 Resource mobilization

This paragraph will discuss the availability of resources for PV in the Netherlands. This will be done by first assessing the available monetary funds for research and development in paragraph 4.7.1. Then, paragraph 4.7.2 will discuss the funds for market stimulation. Paragraph 4.7.3 will explain whether there is enough raw material for the production of the PV-technologies and paragraph 4.7.4 will be dedicated to discuss the developments of the number of employees active in the PV field in the Netherlands. Paragraph 4.7.5 will give conclusions about the resource mobilization in the Netherlands regarding PV.

### 4.7.1 Research and demonstration projects

The first National Solar Energy Program (NOZ) around 1980 did not pay much attention to PV in terms of financial support. This was because the government was not convinced of its viability (Function 4). Research projects on Photovoltaics around 1980 were financed by NWO; companies that were interested in the technology, like Holec and Philips; and the European Community. About 10 scientists were involved in PV research of which 5 were working on cell research and others on related matters (Verbong, 2010). The research, and hence the investments, was mainly on silicon based solar cells, Crystalline silicon on the short-term and amorphous silicon on the mid-term.

The NOZ-PV (1986-1990) spent about 12 million guilders on PV-related research. 24% went to research on poly-crystalline silicon, 12% to amorphous silicon cells, 36% to III-V solar cells, 4% was spent on new concepts and 13 % on balance of the system (BOS) research. BOS (wiring, inverters…) represented 50% of the costs of a PV system, so 13% of the research seemed very little, however the research needed to be done was not as complicated and as expensive as cell research (Verbong, 2001).

The NOZ-PV program 1990-1994 did not convey a clear preference for any of the PV technologies that were available for electricity production. Crystalline silicon cells, amorphous silicon cells as well as the newly invented Dye sensitized cells were financially supported (Verbong, 2001). The total budget increased compared to the previous NOZ-PV to about 50 million guilders. The spreading of the budget over the years can be seen in Figure 4.7.1

NOZ_PV (1997-2000) provided 150 million guilders (about 68 million euro) for stimulation of PV in the Netherlands. About 38.3 million guilders of this budget was for cell research, the rest was mainly demonstration projects and field experiments to stimulate learning processes and stimulate the market (Roos, 2001; van Mierlo, 2002). The subsidies for demonstration projects have become increasingly important since 1995 (van Mierlo, 2002).

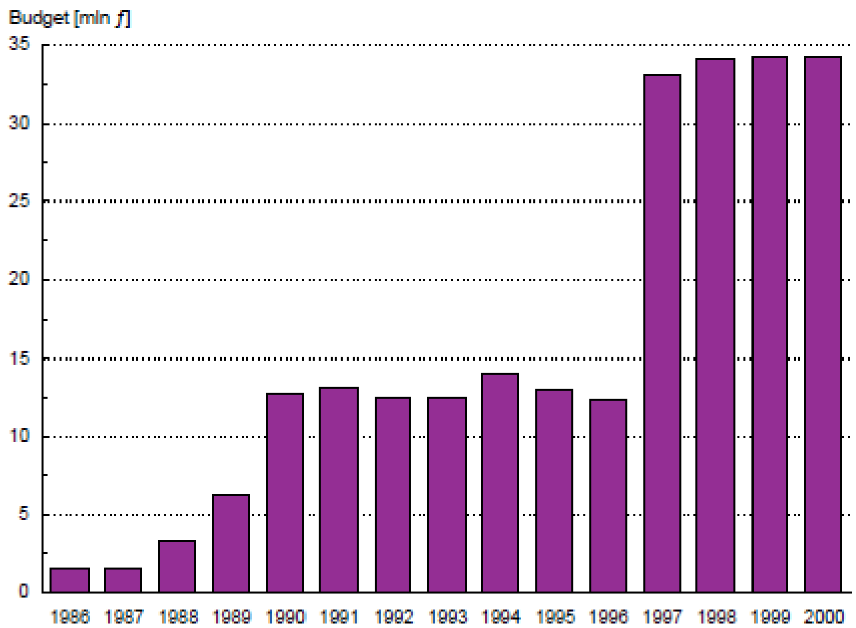


**Figure 4.7.1: Government budget for PV between 1986 and 2000 (EVN, 1997)**

Between 1997 and 2004, the Economy, Ecology and Technology (EET) program was initiated by the government (Negro, 2008). This program stimulated research on technologies that lead to a decrease in CO2 emissions. The EET program granted subsidies to research on Ribbon Growth on Substrate RGS by ECN, tandem cell research and research on a combination of PV and solar thermal energy

(ECN website; EVN, 1997). The EET program was granted 90 million guilders when it began, but different sustainable technologies had to share this amount. The funding also depended on the type of project that was performed. Fundamental research for example received a higher refund in terms of percentage of the costs compared to industrial research.

NOZ-PV went on for while in 2001. After that, the Renewable Energy Programme 2001 (DEN 2001) supported research on PV, next to other renewable energy technologies. Of the nine 9 million euro budget for DEN 2001, 3 million euros went to research projects for PV (PVPS, 2001).

In 2004, an already existing subsidy for research on renewable energy, EOS, was more elaborated and PV received special attention in it. The EOS was divided into different focus groups for research funding:

- NEO, for new research on new unconventional ideas.
- EOS LT, for long term energy research, for technologies that are expected to have an impact between 2010 and 2030
- IS, subsidy for collaboration projects focusing on technology transfer from research to industry
- EOS Demo, which is a subsidy for demonstration projects

The EOS budget for PV was 4 million Euros with two focus subjects. One topic was multi-crystalline solar cells and the other was for thin-film technologies (PVPS, 2005). In 2007, the EOS budget went up to 9.4 million Euros (PVPS, 2007). In 2008 the budget became around 12 million euro. That same year the Innovation Agenda for Energy granted 9 million Euros for demonstration project regarding PV. The Innovation Agenda for Energy had a budget of 438 million Euros for the period (2008-2012) which had to be divided between different renewable energy technologies (PVPS, 2008).

Between 2010 and 2011 the budget for the EOS subsidy was divided as follows:

- EOS LT (2011): 12.5 million euro. 4 million euro for consortia with ECN and 8.5 million for others. The maximum refund per project amounts 1.2 million euro. Fundamental research is 100% refunded (Up until 1.2 million euro); and industrial research is 50% refunded.
- EOS NEO (2010): 1.5 million euro. 1 million for research and 500 thousand euro for feasibility studies. Per feasibility study a maximum of 75% of the project costs is refunded and maximally 45,000 euro can be granted. Non industrial feasibility subsidies are 100% refunded with a maximum of 45,000 euro. Actual researches are granted 100,000 max (50% for industrial projects and 100% for fundamental research).
- EOS Demo (2010): 7.2 million euro. With a maximum of 40% of the project costs and a maximum of 800,000 per project.
- EOS KTO (Short term research): 8.8 million euro. 8 million for research and the rest for feasibility studies. For industrial research 50% of the costs are refunded and for experimental research 25% of the costs are refunded. Medium and small businesses get a higher percentage for experimental research (40%).

The subsidies are for different sustainable energy sources, not only for PV.

Provinces also play a big role in the funding of PV research. In 2010, the province of Noord-brabant announced to invest 71million Euros in PV. 28.2 million Euros went to the Solliance collaboration (see Function 3). Other provinces like Noord-Holland have also supported PV financially (PVPS, 2002), even when the government was not so eager to.

Investments made by FOM in 2010 were mainly in the fields of nano-technology related to PV (21 mln Euros) and organic PV (7mln Euros) (FOM annual report, 2010). FOM and NWO only subsidize fundamental research. ECN for example does not receive NWO or FOM subsidies because their research is intended to be applied in the industry (Kroon, 2011).

The Joint Solar Panel described in Function 3 provides researches each year with subsidies for their research since 2004 (Joint Solar Panel annual report, 2006). Most researches that are subsidized are fundamental and must lead to significant increases in efficiency. Some of the subsidized researches are on Quantum dots, which lead to the generation of multiple carriers per photon, Up and down conversion of photons and improvement of organic solar cells. The investments of the Joint Solar panel between 2006 and 2009 have risen from 3.846 million in 2006 to 7.846 milion in 2009. The rise in budget was mainly because Nuon joined the Joint Solar Panel in 2008 with an investment of 2 million Euros and FOM increased their investment with the same amount of that of Nuon increasing the total amount by 4 million Euros.

The European community also provides subsidies for PV research and projects. ECN, for example receives 60% of their costs back from the European Community for some projects (Soppe, 2011).

### *4.7.2 Market stimulation*

In 1999, Novem launched a program to stimulate the market. This program was called PV-GO! (Schoen, 2001). The goal was to stimulate projects for building integrated PV systems. Projects could get up to 25% of their costs refunded with a maximum of 1 million guilders (Schoen, 2001; Subsidietotaal, 2011). PV-GO was part of the NOZ-PV program 1997-2000.

In 2001, PV became part of the Energy Premium Regulation EPR. Buyers of PV systems could get 3.40 Euros/Wp for their PV systems; and when an Energy Performance Assessment (EPA) is done on their house, they could get an extra 25% refund. The EPR subsidy however had a limit of about 27 million Euro a year (van Mierlo, 2002). In 2002, the EPR subsidy rose to 3.50 Euro/Wp and utility companies also provided a subsidy for their customers of 1 Euro/Wp.

In 2002, a new support scheme for renewable energy was installed, the MEP. This support scheme had very little effect (13 MW in 8 years) as it was only 6.8 cents per KWh, which is almost negligible for PV. MEP was also not in the first place meant for PV but as a bonus on wind energy. The MEP lasted until 2006, but as the subsidy was granted for a period of 10 year, there are still project receiving the MEP subsidy. The EPR was still the most effective market stimulation tool. The subsidy could even reach 4.375 Euro/Wp when combined with the EPA subsidy. EPR therefore led to a significant increase in demand for small PV systems that households could install. Liberalization of the energy market also made utility companies refund their customer’s costs for PV systems with 1 Euro/Wp and a small feed-in tariff on top of that of about 0.20 Euro/Kwh.

By the end of 2003, the EPR budget was depleted and the government announced to end this subsidy which immediately showed its consequences in 2004 when the demand dropped drastically (Function 4). By 2005, there was only one subsidy in the form of a feed-in tariff of 0.097 Euro/Wp which was not very stimulating for the demand.

In 2008, the SDE subsidy was launched which included that 0.30 Euro/KWh was paid to producers of electricity with PV on top of the fossil fuel price for a period of 15 years. The total amount of subsidy granted in the year 2008 was 79 million euro. The granted subsidies for small systems (0.6-15 KWp) in 2009 amounted 75.8 million euro. The granted subsidies for large systems (15-100 KWp) were 54.5 million euro (Agentschap NL Jaarbericht, 2010). For small systems about half of the feed-in tariff was paid by subsidy and the other half by the utilities. For bigger systems (>100 KWp), the utilities only had to pay 0.076 Euro, the rest was by paid by the SDE subsidy. In 2010 the granted subsidies were 68.5 million euro for small systems and 24 million euro for large systems. By the end of 2010, the SDE subsidy was ended in anticipation for a SDE Plus subsidy which would only support large systems with a lower subsidy (0.15 Euro/KWh).

The total amount of PV power that was granted a subsidy by 2010 reached 82 MW. The subsidies in this case are MEP and SDE together. 31 MW of this power was installed by 2010 which means that 53 MW has not been realized yet. Of the 31 MW, 18 MW was with help of SDE and 13 MW with help of the MEP. For MEP there is still 1 MW of PV systems that need to be realized and for SDE there are still 51 MW of PV systems which are not installed yet (Agentschap NL Jaarbericht, 2010).

Entrepreneurs who invested in sustainable technologies could count on tax refund EIA and VAMIL since 1997. With this subsidy, entrepreneurs could deduct 41.5% of the investment from their taxable profit. The total budget or this subsidy for 2011 is 151 million Euros.

SBIR-IPZ (Small Business Innovation Research – Innovatieprogramma zonnestroom) is an initiative by the ministry of economic affairs for which the opportunity for requests ended in 2010. This initiative is focused on small businesses that can come up with innovative practical solutions to ease the adaptation of PV in the built environment. Examples are better techniques to establish solar panels on rooftops and integration of cells into glass. The total budget granted for SBIR-IPZ was 3 million euro. The projects can have a duration of maximally 2 years.

### 4.7.3 Availability of raw material

As already mentioned in paragraph 3.4, there is no shortage in solar grade silicon anymore. Solar grade silicon is not produced in the Netherlands but there are plans for a factory as mentioned under Function 1 in paragraph 4.2. Indium and Tellurium are scarce materials. That can lead to a price increases once the CdTe and CI(G)S are produced on a large scale. Supercis solar a very recently established company (2011) is planning to produce CIGS. The materials needed are going to be imported (van der Vleuten, 2011). Organic PV materials are not scarce (Marsh, 2008). Fullerene, the material needed to produce polymer organic solar cells is produced in the Netherlands by a company called Solenne (Kroon, 2011).

### 4.7.4 Employment in the PV field

The number of people who are active in the field of Photovoltaics rose between the year 2004 and 2009 from 147 to 588 (CBS, 2006; CBS, 2009). The number of people active in R&D rose during the same period from 23 to 56. The number of people active in the production of solar panels rose from

21 to about 370. These numbers are depicted in Figure 4.7.2. The data provided by Statistics Netherlands encompasses the whole PV industry and is not categorized by type of technology. The data per technology was not available at Statistics Netherlands. Looking at the previous functions it can be concluded that the employment in production and “other” in Figure 4.7.2 must be for crystalline silicon as this is the only produced technology in the Netherlands and the mostly installed.

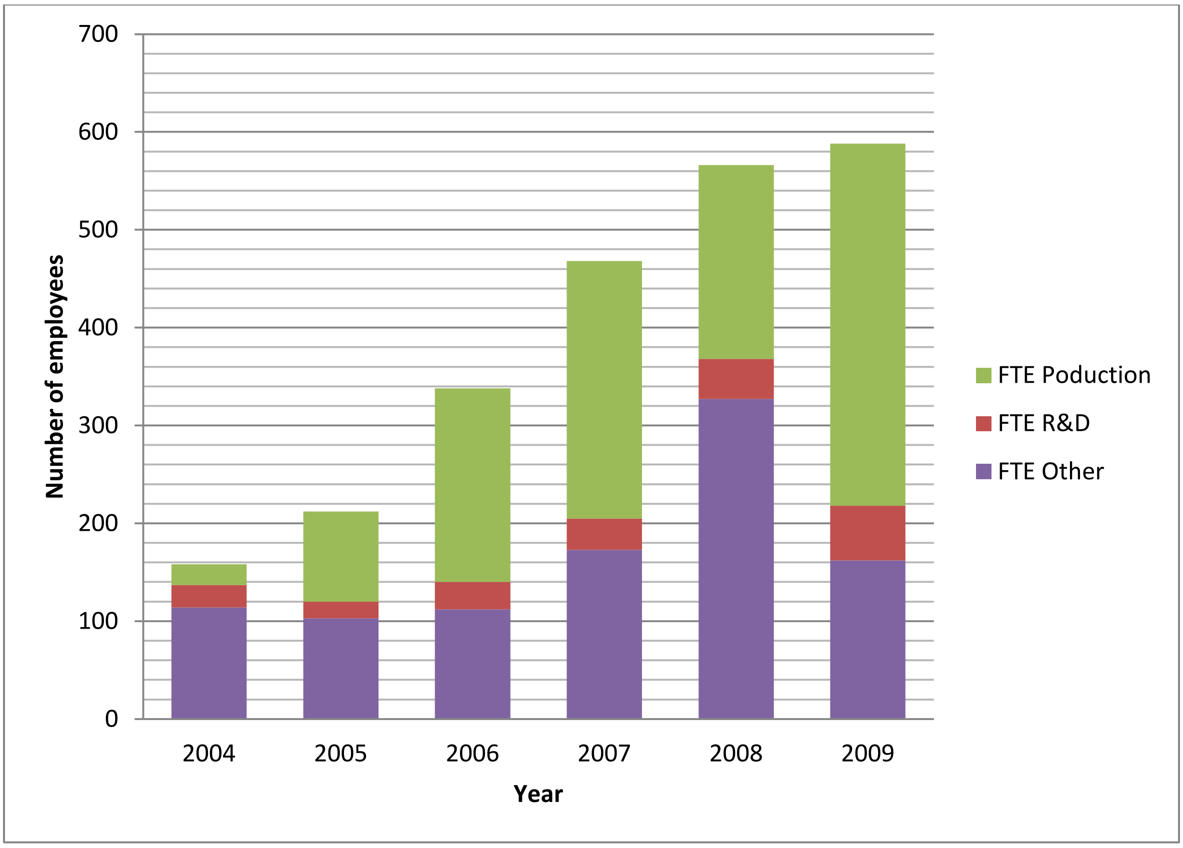


**Figure 4.7.2: Development of the number of employees in the field of PV (Data gained from CBS, 2009 and CBS, 2006)**

### *4.7.5 Conclusions Function 6*

The first researches done in the Netherlands were financed by NWO as it was mostly fundamental research around 1980. The research was done on crystalline and amorphous silicon. Back then Amorphous silicon was seen as the mid to long term alternative.

After lobbying from different parties, PV had the attention of the Ministry of Economic Affairs around 1986 and they started subsidizing research through NOZ-PV, mostly on crystalline and amorphous silicon again. NOZ-PV budgets were rising until the year 2000 and after 1995 demonstration projects have become increasingly important receiving about half of the granted subsidies during NOZ-PV 1997-2000.

The technology that provided the highest employment in the Netherlands is the crystalline silicon technology. This is because this is the only technology that is produced in the Netherlands and which is mostly installed.

After NOZ-PV there were several other subsidy programs though not especially for PV. Several different renewable energy technologies had to share the subsidies. There are however more different funds for research which kept research in the Netherlands on a high level. All kinds of research are supported from fundamental to industrial research. Subsidies that stimulate the market through industrial and applied research have gained more importance the last years as can be noticed from EOS and SBIR-IPZ.

## 4.8 Function 7 Creation of legitimacy

During the seventies lobbying was done by the few scientists working on PV like Daey Ouwens. Around 1975 the government was not yet fully convinced of the usefulness of PV on the short term.

The International Solar Energy Society (ISES) department in the Netherlands argued that the Netherlands will fall behind regarding research on PV. The research done in the Netherlands was not enough according to them. Therefore, in 1982, the board of ISES demanded the Ministry of Education and Science to stimulate and widen the research on Photovoltaic energy. The Ministry asked ISES to come up with a proposal for a research program. ISES delivered the proposal and asked for PV research to be part of the NOZ. For the program, which should last between 1980 and 1984, 6 million guilders were needed to do research on polycrystalline silicon, amorphous silicon and for the long term III-V solar cells. Unfortunately for ISES, the responsibility of Technology and science turned to the Ministry of Economic Affairs. This latter was more in favor of nuclear energy since it was cheaper and more stable which was not the case yet for PV.

In 1983, Holland Solar was established. This organization functioned as a meeting point for different actors in the solar energy industry. Not only PV, but also solar thermal energy. The organization counts at the moment about 100 members of which 60 for PV. Holland Solar established collaborations between them and several international and European organizations like ISES and IEA. They organized many conferences throughout the years (Holland Solar website). Their (inter)national collaborations certainly led to an increasing influence of their lobby activities. However, as solar thermal was also a great part of Holland Solar’s program, PV had to share the focus of the lobbying with solar thermal technologies. Holland Solar lobbies for better and stable subsidies and a better appreciation of PV in the ratings for buildings (Veenstra, 2011). They do this by having contact with ministries and members of the parliament. They also have contact with ECN who in their turn advise the government on subsidies and other energy related matters (Veenstra, 2011). Holland Solar is also developing an educational program for PV installers to improve the quality of PV systems installed in the Netherlands.

During the late eighties, the awareness of the limited amount of fossil fuels on earth increased the attention to sustainable energy sources. ISES took advantage of that situation to lobby for PV again. ISES argued that too much attention was given to wind energy which led to neglecting other important sustainable energy technologies like PV (Verbong, 2001). ISES also demanded the Ministry of Economic Affairs to formulate goals they want to achieve with PV in order to give people (companies) clear expectations regarding their opportunities and possibilities with PV. The fossil fuels depletion, the environmental problems and the lobbying of ISES changed the opinion of the Minister of Economic Affairs. In 1990, the minister praised PV as one of the most important sustainable energy technologies in the future especially after 2010 (Verbong, 2001).

Because Daey Ouwens was active in the province of Noord-Holland in the Provincial Bureau of Energy PBE around 1990, he lobbied the province to invest in demonstration projects in developing countries which would show the viability of this technology. As these projects have been successful, they also contributed in changing the opinion of the Ministry of Economic Affairs in favor of PV.

In 2001, a manifesto was signed by 72 organizations that were active in the field of PV. The main goals were to make the EPR subsidy accessible for everybody, also property developers. These were not given EPR subsidies because that was only for parties paying an Ecotax. Besides, they asked for higher EPR subsidies and a feed-in tariff (PVPS, 2001; Hendrikgommer, 2011; nieuwsbank, 2001). As a result the government decided not to enforce the PV covenant they signed with actors in the PV field again.

In 2002, four organizations ECN, TNO-Bouw, Projectbureau Duurzame Energie and Duurzame Energie Federatie; lobbied for improvement of the EPR subsidy and the EPA tax refund to encompass more sustainable activities within the built environment i.e. PV. They argued that there were many unutilized opportunities to increase the share of sustainable energy (EVN, 2002; Verklaring van Rotterdam, 2011). For example the availability of many square Kilometers of rooftops that could be used for PV systems. They also lobbied for more R&D subsidies that can lead to the invention of cheaper production and installation methods.

Since 2003, owners of PV systems and proponents of PV can join the Association for solar energy producers (in Dutch Zonnestroom Producenten Vereninging ZPV). This association provides their members with help and advice on the acquirement of PV systems and how to apply for subsidies. They also lobby for clear regulations and subsidy schemes. At the moment the association has about 1351 members producing together an amount of about 2.9 Megawatt. They started because the initiators were fed up with the changing subsidies and wanted to represent the customers in this case. They also supported customers that had problems with their energy providers who delivered them malfunctioning PV systems. They succeeded in getting their customers helped in that case (Wouterlood, 2011). ZPV has contacts with people in AgentschapNL and people in the parliament if they want to be heard. They also write articles and attend fairs. They lobbied for more refunds by the utilities with help from other organizations and succeeded in increasing the refund to 5000KWh.

According to Edwin Koot founder of Solarplaza in an interview with Energiebusiness, lobbying for PV in the Netherlands is difficult. This is because the market is not yet strong enough to be able to raise enough capital to finance the lobbying (Energiebusiness, 2011). Lobbyists for the established energy sources have more money and PV lobbyists can hardly compete against them. However, in 2011, ECN together with Brabantse Onwikkelings Maatschapij (BOM) initiated to form a cluster between different companies and research institutes involved in PV. The cluster is called the Solar Industry Platform and the aim for it is to serve as an interaction link between the companies in the PV industry, their customers and especially the government. Many actors in the industry have noticed that the government is not up to date and does not know the importance of the PV industry for the Netherlands and how far developed it is. The Joint Solar Platform will therefore take the task of informing the government and lobbying for regulations that will encourage the use of PV in the Netherlands (Solar Magazine, 2011). The companies that are part of the cluster for the moment are: ECN, BOM, Helianthos, OTB Solar, Scheuten Solar, Avantor, Eurotron, Mastervolt, Smit Ovens, Solar Modules Nederland, Solland Solar, Sunergy, Tempress Systems and Ubbink Solar. Most of the people interviewed for this thesis and who were active in these companies were not aware of this cluster. This means that the cluster has not made any significant achievements yet.

### *Conclusions Function 7*

Lobbying was done during the seventies by scientists who saw great opportunities with PV. The lobbying was mostly done in order to obtain financial support in order to be able to perform researches. Then 1982, international organization like ISES started to lobby the Dutch government to consider PV in their R&D financing. The government's response was not very positive. Later on during the late eighties, when the government realized the limited amount of fossil fuels the lobbying of ISES was more fruitful.

Several organizations have been established to lobby for clear regulations and subsidies. These organizations mostly have contact with the end-market consisting of distributers, installers and consumers. Joined efforts have led to a higher refund for produced electricity. But subsidies are still being negotiated.

The industrial companies have recently joined forces in a cluster that should represent the PV-industry and serve as a link between them and the government. No real significant results have been reached yet. This can be concluded as most people interviewed that were working in the involved companies did not know anything about this cluster.

Lobbying was not done for a specific PV technology but for PV in general. First for research funding, and then for improving the situation for the market and the customers.

# 5. Motors of innovation

This chapter will analyze the interconnection between the functions of innovation systems of each PV technology in the Netherlands and the dynamics of these functions. Using these interconnections between the functions over time, motors of innovation, explained in paragraph 2.3, will be identified.

## 5.1 Crystalline silicon

When looking at Table 4.1 that belongs to Function 4 (Guidance of the search) in paragraph 4.5, several slightly different periods can be defined. Combining these periods with happenings from the other functions of IS, one can identify three periods. The first represents the very beginning, where research took off and c-Si PV started become an option through some entrepreneurial activity. The second period is when the innovation system of c-Si seemed to be flourishing. The third period, is when the innovation system of c-Si starts to crumble off.

### *5.1.1 Function dynamics*

**The beginning 1975-1985**

Research on c-Si started during the fifties [F2]. The promising results [F4] made scientists lobby the government for more research funding [F7]. This did not work out during the seventies as PV was not considered to be a viable sustainable energy solution for the Netherlands [-F4]. This made the government turn its attention towards other technologies like wind and solar thermal [-F4,-F6]. The little research that was done was financed by NWO as being fundamental research [F6]. Lobbying from international organization [F7] did not change the mind of the government in the early eighties. As investments in energy were the responsibility of the Ministry of Economic Affairs, nuclear energy was the favorite because it was much cheaper. Despite the negative attitude of the government, the company Holecsol was established in 1982 producing crystalline silicon solar cells and panels [F1]. Holec started to cooperate with several universities to improve efficiencies of their c-Si cells under coordination of FOM which was part ZWO [F2, F3]. Holecsol also started the first demonstration project in 1983 [F1] to show the possibilities with PV. International developments made the Ministry of Economic affairs willing to invest in R&D on PV but only to keep up with these international developments and not to miss the boat once this technology turns out to be a success [F4, F6]. Meanwhile R&S (Shell Solar) looked to create a market abroad in developing countries to prove the usefulness of technology.

**The rise 1985-2003**

In 1985 80% of the revenues of Dutch PV companies were made abroad. Only 20% of the revenue was made in the Netherlands, mostly on autonomous systems for which PV was less expensive than a connection to the grid (yachts, buoys, cattle drinking troughs) [F5].

Environmental problems and the rise of fossil fuel prices [F4] gave the opportunity for new lobbying activities by ISES and scientists like Daey Ouwens to stress the importance of PV again during the end of the eighties [F7]. Even though the ministry was still more convinced of the possibilities with wind energy, PV systems were partially refunded with the SES subsidy which was actually not specifically for PV [F6]. A roadmap made by Shell praised PV to be very important in the future and specialist argued that PV has seen tremendous price drops [F4]. Besides, other sustainable technologies have not proven to be as successful as expected [F4].This made the minister announce that PV was indeed a very promising energy alternative [F4]. The budget of the NOZ-PV therefore increased by about 50 million guilders [F6]. The result was a continuation in research and the initiation of several demonstration projects aiming to prove the efficiency of connecting PV systems to the grid [F1, F2]. Until 1996, there was only one cell and panel manufacturer which was Shell Solar. This latter provided most of the panels needed for the many demonstration projects initiated during the nineties. These demonstration projects have led to knowing the technology better by the targeted end users and gradually made them realize the benefits [F1] →[F4]. After 1996, Shell Solar started to face competition from companies like BP and Kyocera. These companies did not manufacture their products in the Netherlands but only delivered their panels to distributors [F1]. NOZ-PV 1997-2000 again provided financing [F6] for multiple researches on cells and increasingly on demonstration projects [F1,F2]. Research on c-Si continued, mainly by Shell and ECN. Through the PV covenant [F4], entrepreneurial activity was encouraged [F1] because the government herewith expressed their support for activities related to PV. In 1998, it was legally arranged that producers of renewable electrical energy could set off 3000 kWh against what they have used from the grid to encourage (and protect) renewable energy producers [F5]. This amount was later on increased to 5000 kWh. In 2001, the EPR subsidy was introduced [F6]. This subsidy was for small systems mainly for households [F5]. This of course encourages entrepreneurial activity especially for distributors, installers and panel manufacturers [F1]. Large project developers did not receive the EPR subsidy. This made the realization of very big projects difficult [-F1]. The Ministry of economic affairs was however again not very confident about the role of PV in the Netherlands [-F4]. Utilities on the other hand encouraged PV by providing about 1 euro/Wp fo PV systems to show their involvement in green energy [F6].

In 2003, Shell Solar decided to leave the Netherlands due to insufficient demand [-F1]. The same year Solland Solar started manufacturing c-Si cells and Ubbink Solar Modules started producing c-Si panels [F1] around the same period.

**The breaking down 2003-2011**

In 2004, the EPR subsidy was ended [-F6]. This immediately showed in the demand for solar panels [-F5]. Solland Solar and Ubbink were growing but most of their turnover was made by exporting their products to European countries. Many other companies ended their activities in the Netherlands [-F1]. The MEP subsidy that was initiated in 2002, realized 13 MW up to 2011. The SDE subsidy realized 18 MW since 2008 with 51 MW still remaining to be installed. Since 2008 there is a clearly increasing additionally installed PV capacity. This is especially due to the SDE subsidy. The SDE budget has been surpassed several times due to the high demand, so people are interested. However, the subsidy is now cancelled and replaced by SDE+ which only supports big PV systems. Whether this subsidy is going to be more successful is still to be awaited. Especially since the Netherlands, being a small country, does not have big unused spaces that could be exploited for large PV systems.

Research is, and always has been since the late eighties, sufficiently supported through financing. The government now is also aiming to stimulate the market by supporting small businesses that come up with viable ideas. The government seems to think that the market should be stimulated in that way instead of subsidizing the owners of PV systems. What shows the instability of the Dutch (c-Si) PV market is the fact that Ubbink Solar Modules had to close down after the bankruptcy of Ecostream [-F1] if it was not taken over by Ubbink (Story can be read at Function 1). Solland Solar underwent a management buy-out and is thinking to switch to the production of panels. If this goes through, the Netherlands would not have any cell producers [-F1] and the value chain in the Netherlands will decrease [-F1]. C-Si panels and cells from Asia are cheaper. In combination with a weak Dutch home market, the troubles can be noticed due to the aforementioned events. Nevertheless, machine manufacturing companies like Smit Ovens and OTB-Solar are quite successful and are the proof of the strength of the Dutch knowledge capacities regarding c-Si; and how this knowledge can be turned into value. This stimulates research and explains the increasing involvement of these companies with activities within the innovation system [F2, F3].

### 5.1.2 Identified motors of innovation

The dynamics of first period (1975-1985) showed much similarity with the "science and technology push motor". This is in the sense that c-Si cell technology was an emerging technology and especially scientists were realizing the possibilities through their research [F2,F3]. So guidance of the search [F4] started by expectations from scientists [F2,F3]. This led to R&D programs financed by the government (ZWO, which was part of the Ministry of Education) [F6]. As with the science and technology push motor, entrepreneurial activity [F1] was weak and a few demonstration projects took place to prove the usefulness of the technology. These demonstrations perhaps triggered the government. Together with international scientific developments, this led the government to agree that perhaps in the future PV could be lucrative [F4]; and started to support the technology financially [F6]. Figure 5.1 shows how the motor of science and technology push came into force.

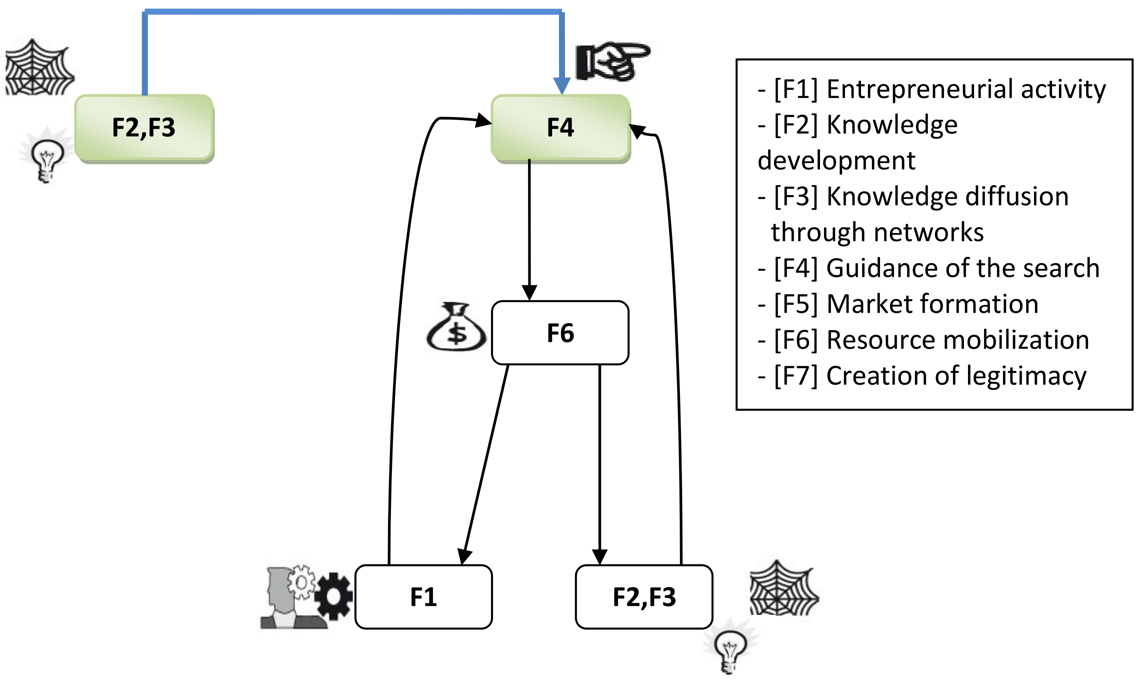


**Figure 5.1: The science and technology push motor of c-Si technologies (1975-1985)**

The second period showed characteristics of an Entrepreneurial motor. All elements from the STP motor were present, which is a sort of pre-condition for the entrepreneurial motor. [F4] is strengthened by the concerns of the government regarding environmental problems. This gave the opportunity for ISES to lobby again [F7]. Entrepreneurs at first got the opportunity to start projects in sunny developing countries with help of subsidies from the government [F6],[F1]. These developing countries were a niche market in which the technology could prove its real use [F5]. As mentioned in the description of the entrepreneurial motor, the niche market of the entrepreneurial motor is not really part of the TSIS but provides a positive influence on the rest of the functions within the TSIS. Since the technology is applied abroad it is not really part of the TSIS of PV in the Netherlands.

Successful projects abroad led to more confidence in the technology [F4] and many demonstration projects in the Netherlands followed [F1] showing the possibilities especially with grid connected PV systems. The demonstration projects acquainted the end users with the technology and gradually made them interested in it [F4].Then, more distributers of c-Si PV technologies started selling also foreign technologies. This increased the interest in PV even more [F4] and then Subsidies for users followed [F6]. That increased the demand [F1]. Companies like Shell solar were very close with academia and research institutes [F1,F2,F3]. Figure 5.2 shows the motors identified for c-Si technologies in the second period. As mentioned earlier most of the dynamics are that of a Entrepreneurial motor. [F1] was strengthened through more demonstration projects and more companies; and networks between researchers and companies became stronger and interactive. However, [F7] was not really part of the feedback loop between [F1] and [F6]. Lobbying was weak and was only effective in combination with windows of opportunity created by environmental problems and international (technological) developments. A direct feedback loop from [F4] to [F1] like in figure 2.5 is difficult to identify. This is because subsidies are always needed. Demonstration projects needed subsidies [F6] but also customers needed subsidies, else the technology would be too expensive [F6] → [F1].

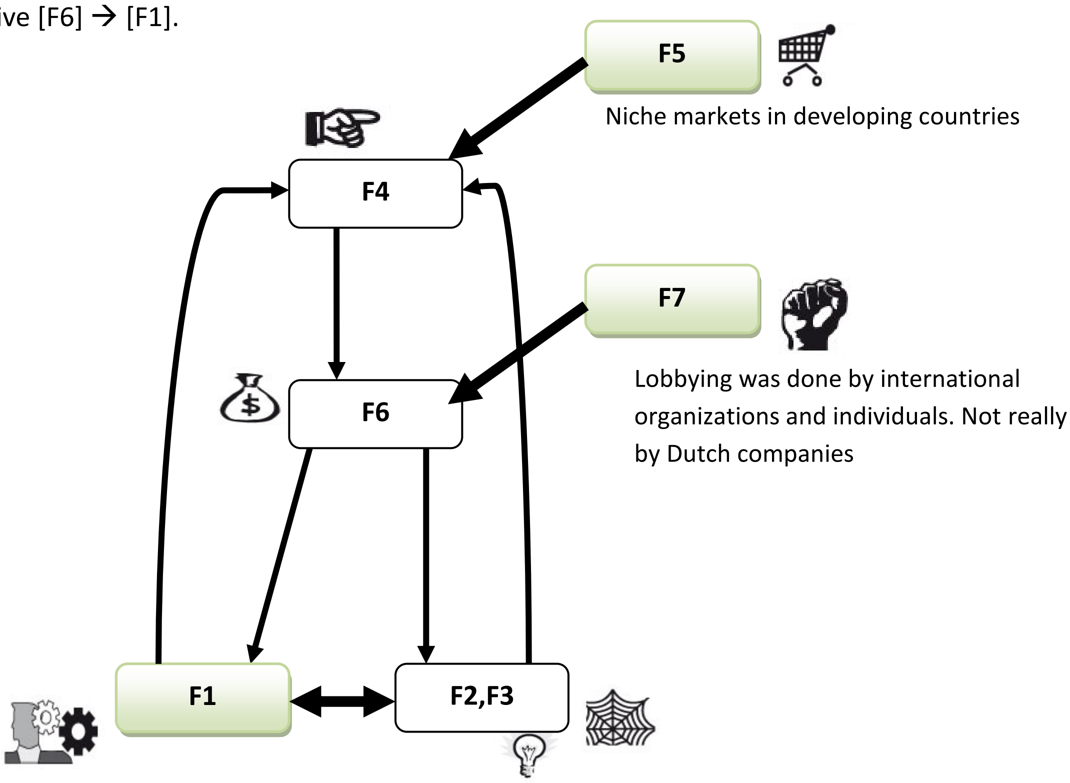


**Figure 5.2: The entrepreneurial motor of c-Si technologies (1985-2003)**

The subsidies encouraged entrepreneurial activity especially for distributers and installers. Project developers, however, were only discouraged as the EPR subsidy did not hold for them even though they could be significant contributors to the diffusion of PV [-F4,-F1]. The end of the EPR subsidy [-F6] for all consumers led to the downfall of demand and hence entrepreneurial activity [-F1]. When entrepreneurs are weak their lobbying activity decreases and has no influence [-F7]. These are all signs of a motor of decline and the start of the third period (2003-2011). On the other hand, research is still well subsidized and there is still collaboration on R&D [F2,F3, F6]. So, the motors of decline only hold for entrepreneurs active in panel and cell manufacturing and distribution. Machine manufacturers have even seen a rise in demand for their products, but, from abroad.

A significant rise in additionally installed capacity came in 2008 by the introduction of the SDE subsidy [F6]. Mostly the distributor and installation companies are profiting from this demand; as the manufacturing companies like Solland Solar and Ubbink Solar still sold respectively 100% and approximately 90% of their products abroad. Solland Solar underwent a management buy-out and is probably going to focus on module manufacturing to increase the number of possible customers. This shows that there are still a lot of changes and developments regarding Dutch companies and they still rely heavily on export even though there has been a rise in demand. This demand is very dependent on subsidies and apparently most panels are imported since the amount of panels manufactured for the home market by Dutch companies are lower than what has been installed in the last 3 years. This makes the home market very unreliable, hence the focus on export again.

Regarding the gap that exists between manufacturers and the home market, but still the importance of research on c-Si in the Netherlands, The last period (2003-2011) showed some signs of a motor of decline back towards a science and technology push motor. It is true that there are even a few hundreds of PV panel distributors and installer (Veenstra, 2011). However, they lack the proper skills and experience which indicates that PV is not their core activity and their addition to the TSIS is insignificant. It looks more as if the market is detached from the TSIS. The Dutch PV market is not profiting from the developments in the Dutch scientific field. Installers and distributors are represented by Holland Solar and customers are represented by ZPV, but that did not lead to stable and clear subsidies. So function [F7] is insignificant again. The benefits of c-Si PV are known and proven in the past so niche markets [F5] are not something that could change the expectations. Entrepreneurial activity is weak inside the Netherlands and focused on export. This results in the motor of STP depicted in Figure 5.3. The influence of [F5] and [F7] disappeared and [F1] is weakened. But there is still a strong connection between entrepreneurs and researchers. Not the entrepreneurs that are active in installation and distribution but the ones active in cell production and machine manufacturing. Therefore the motor of decline resulted in a STP motor with a strong connection between some entrepreneurs and the research field.

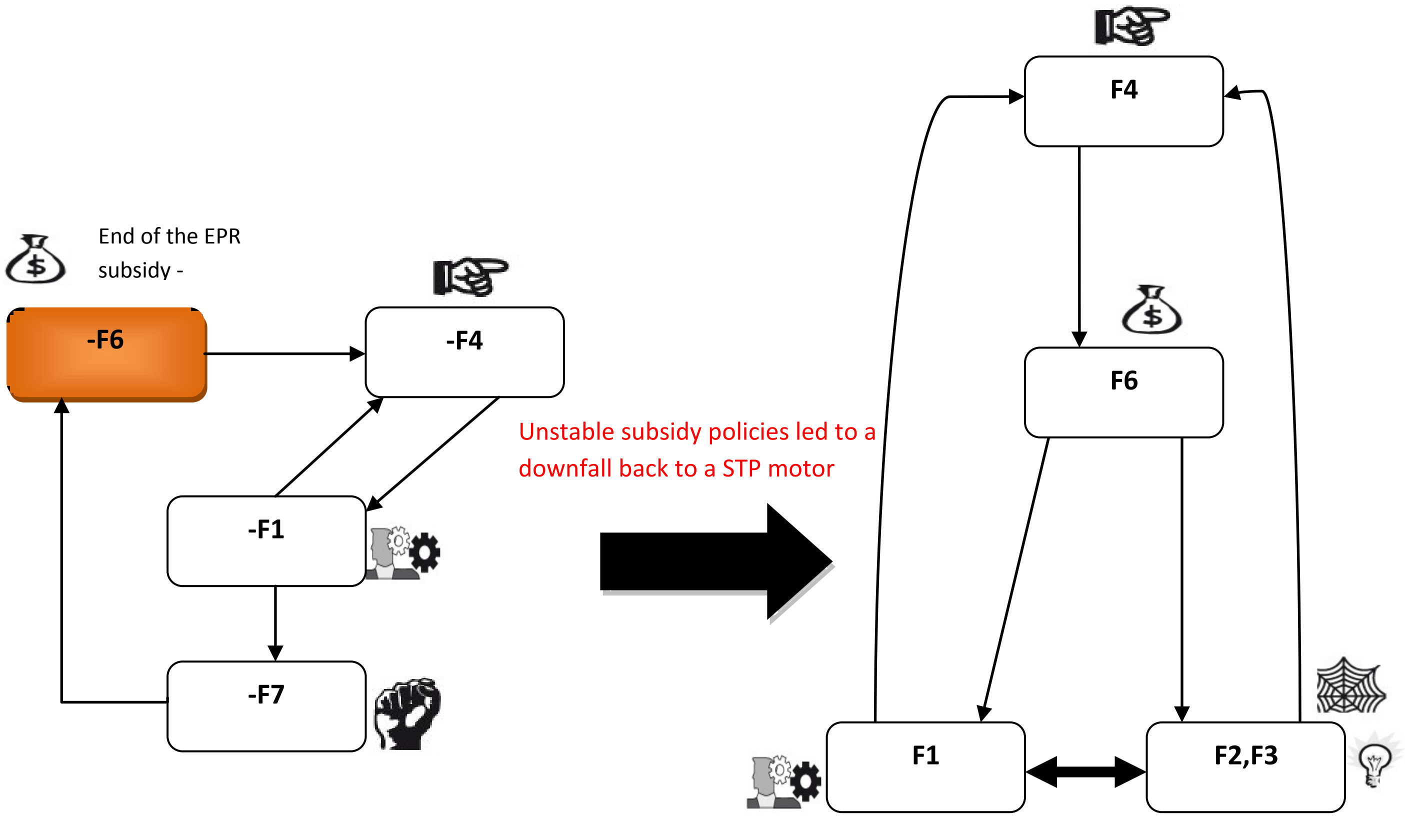


**Figure 5.3: Motors of decline result in a STP motor for c-Si technologies**

## 5.2 Thin film silicon

### *5.2.1 Function dynamics*

Thin film silicon PV technologies followed a similar path as c-Si technologies regarding financing and expectation from the government. This entails that thin film silicon technologies have seen similar dynamics starting with guidance of the search due to environmental problems [F4]. The support of advocacy coalition was weak, but environmental problems and international developments formed a window of opportunity [F7] that made the government realize the possibilities [F4] and provide financial support for research and projects shared by different parties [F6, F2, F3].

There has never been a distinction between owners of c-Si panels or owners of thin film PV (thin film silicon, CI(G)S, CdTe). Even the small difference in financing from for example NOZ-PV was because c-Si was more mature and it also needed financing for more applied research. Therefore the rise of the thin film silicon technologies' TSIS is similar to that of c-Si, starting with research around 1974 by universities and fundamental research organizations. The research was mostly academic with financing from ZWO's FOM and coordination from ZWO. Thin film silicon technologies have for a long time been seen as the successor of c-Si [F4]. Entrepreneurial activity was lacking. This was mainly because efficiencies are much lower than c-Si cells and a lot of research was still needed to improve that and treat degradation effects of the material.

By the end of the nineties Entrepreneurial activity started, but not in a very strong manner [F1]. Free Energy Europe was established in 1998 but manufactured a-Si panels for developing countries and the production took place in France; and Akzo Nobel started the company now known as Nuon Helianthos in 1999. Akzo Nobel planned to start a pilot line around 2002. By 2005 this still did not happen [-F4]. Free Energy Europe was sold to another company that went bankrupt in 2009 [-F1]. Nuon Helianthos has up until now been looking for investors. In Oktober of this year (2011) they were closed down [-F6] → [-F1]. Demonstration projects are almost absent and one that has been done in Zwolle showed that it would not be possible without subsidies [-F4]. Machine manufacturers also informed that some of their international customers are dropping a-Si production (van der Gugten, 2011). This certainly harms the image and expectations of the technology in a negative way [-F4]; and hence affects the willingness of investors in the Netherlands to invest in thin film silicon production lines [-F4] →[-F6] → [-F1]. Research on thin film silicon is still being executed though. Research projects are still being done and initiated; and there are many collaborations on the topic [F2,F3]. Some major developments are necessary for thin film technologies to be commercially attractive again to encourage investments and entrepreneurial activity.

### 5.2.2 Identified motors of innovation

Thin film silicon had seen the same start as c-Si. Starting with guidance of the search [F4] leading to financial support by especially the government [F6] which in turn led to research [F2] and researchers worked together and shared information [F3]. Entrepreneurial activity is and was weak or can be even considered absent. These are all signs of a motor of science and technology push.

Since 2005, the TSIS of thin film silicon is showing more signs of a motor of decline. Developments in other thin film technologies and c-Si showed that thin film silicon technologies were not the ultimate successor of c-Si technologies because significant results were lacking [-F4]. In other words, the expectations were perhaps overstretched. As the main application for solar panels are rooftops, which are small spaces, efficiency is important and thin film silicon is lacking that compared to other technologies at the moment [-F4]. Nevertheless, there are still networks of researchers active with thin film silicon showing results that can lead to changes in the lowering expectations. Therefore, the decline so far is more regarding entrepreneurial activity and investment in companies. Leaving the TSIS rely mainly on [F2], [F3], [F4] and [F6]. With [F6] in the form of governmental financial support and [F4] as being still an option once efficiency is sufficiently increased in combination with the possible disappointing results for other thin film technologies. Therefore, there is a kind of motor of science and technology push with clear barriers to entrepreneurial activity. This is depicted in Figure 5.4.

The fact that less of the abundant silicon material is used makes the technology an interesting option [F4]. This leads to subsidies to perform research by academia, research institutes and companies that work together [F2, F3]. The local and international developments are however not fast enough and no hole in the market could be found for thin film silicon in the Netherlands. This, together with developments of other technologies, made investors hesitative to invest in companies with this product. Therefore there are two arrows departing from guidance [F4]. One bold arrow because of the vast possibilities in research; and one interrupted arrow showing the disappointing (international) results. This latter makes investors look for other investments, hence the feedback arrow of [F6] back to its origin without reaching [F1]. The negative [F1] in its turn weakens the expectations.

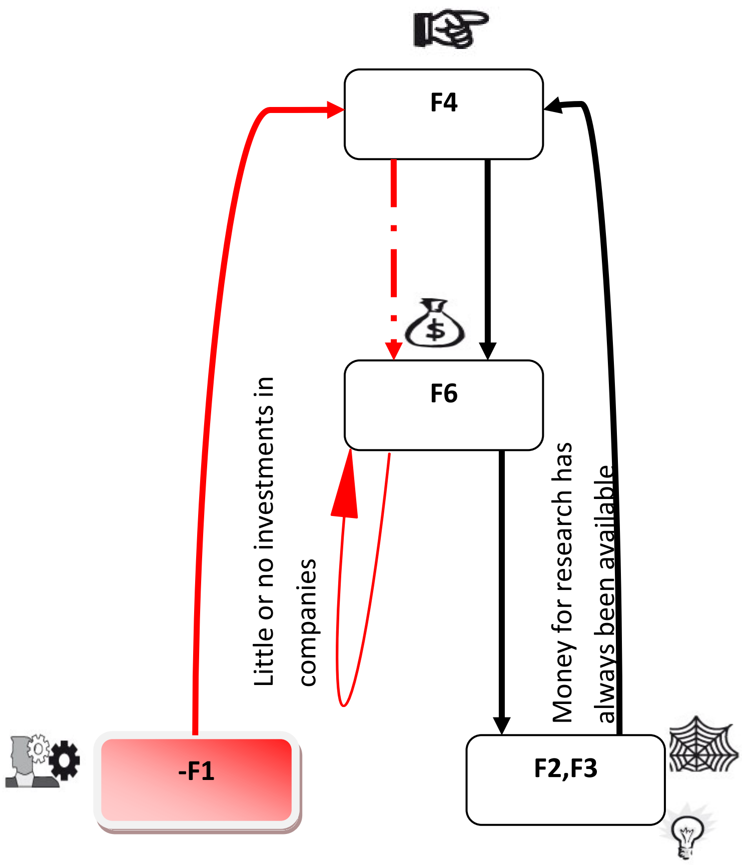


**Figure 5.4: STP motor for thin film silicon technologies**

## 5.3 CIS and CIGS

### *5.3.1 Function Dynamics*

During the seventies, following c-Si and thin film silicon technologies, possibilities with CIS were explored [F4] → [F6]→[F2]. According to the data there were not many collaborations regarding CI(G)S. CI(G)S were not as "popular" in research as c-Si and thin film silicon technologies. So, the little collaboration was due to the minimal research done on the topic. ECN, which can be considered as the spider in the web when it comes to PV, did not want to work on CI(G)S because it contains Indium which is a scarce material and that clashes with the whole idea of sustainable energy [-F4] → [-F2, -F3]. The technology got increasing attention in the Netherlands after the year 2000. This was mainly due to positive international developments [F4] and perhaps the slow developments of thin film silicon [F4] which was considered the direct successor of c-Si. Scheuten Solar developed a new CIS technology and opened a pilot factory [F2]. Scheuten Solar worked together on this technology with TNO-TPD and OTB [F3]. Since 2010 the consortium of Cigself was established consisting of several big players in the PV field [F3]. The aim is to establish a pilot production line where CI(G)S production technologies can be tested and improved. In addition, some companies are established looking to exploit the CIGS market by looking into possibilities for CIGS production [F1]. Machine manufacturers are also profiting from the international demand for production technologies of CI(G)S. They are also important for knowledge diffusion through networks regarding this technology as most machine manufacturers are part of Solliance and Cigself.

### *5.3.2 Identified motors of innovation*

Again, CI(G)S profited from the same windows of opportunity of c-Si and thin film silicon technologies. However network formation and little entrepreneurial activity started by the end of the year 2000 [F2][F3] in the form of a collaboration to start the pilot line for Scheuten Solar. The parties involved have already been active in PV for a longer time though.

Now due to promising international developments [F4] more networks are formed between Dutch companies and research institutes. This specific network formation started out as initiative from research institutes and universities. This can be concluded because Cigself is part of Solliance which is initiated by universities and research institutes. Cigself is considered to be an important alliance in which CI(G)S can be developed. The companies that joined Cigself were active in fields related to CI(G)S production and think they could benefit from the collaboration. The alliance started in 2010 and the common lab to test the technologies is almost ready. 2010 is herewith the year when collaboration really started and belief in CI(G)S became strong enough. And Therefore, 2010 can be considered as the start of the science and technology push motor enforcing the CI(G)S' TSIS.

Before 2010, there was not really a TSIS regarding CI(G)S. This TSIS is not to exploit the home market but purely because there could be an important international demand for the product or better said: for the production processes that are involved. The entrepreneurial activity that will start because of this collaboration will mainly be in the machine manufacturing business. What was not mentioned in any of the functions of TSIS described in chapter 4, is that Scheuten also initiated a joint venture with a company from Taiwan. This joint venture is to produce CIGS in Taiwan (Ritek, 2011). This indicates that even though Scheuten is collaborating with research in the Netherlands, their goal is to produce abroad. This again show that entrepreneurial activity in the Netherlands will be mostly around production technologies and not the actual production of CI(G)S.

The STP motor for CIGS is depicted in Figure 5.5. Because research on PV was already being done for a long time in the Netherlands, the triggers for the start of the STP motor were formed by several functions at once, namely [F1],[F2],[F3] and [F4]. These functions in fact were not a result of each other but were already existing because of developments of c-Si and thin film technologies. The functions then enforced each other in the case of CI(G)S. [F2] and [F3] were already formed since many universities, institutes and companies worked on PV. Scheuten Solar started with c-Si abroad and then started a CIS pilot factory [F1]. Also machine manufacturers were involved in CI(G)S because of their expertise in semiconductor material and other PV technologies [F1]. This, together with the expectations for CI(G)S [F4] started the STP motor. Because the Netherlands was so active in PV technologies [F1,F2,F3] and because the expected possibilities with CIG(S) [F4], the step to start a large collaboration on CI(G)S was easy.

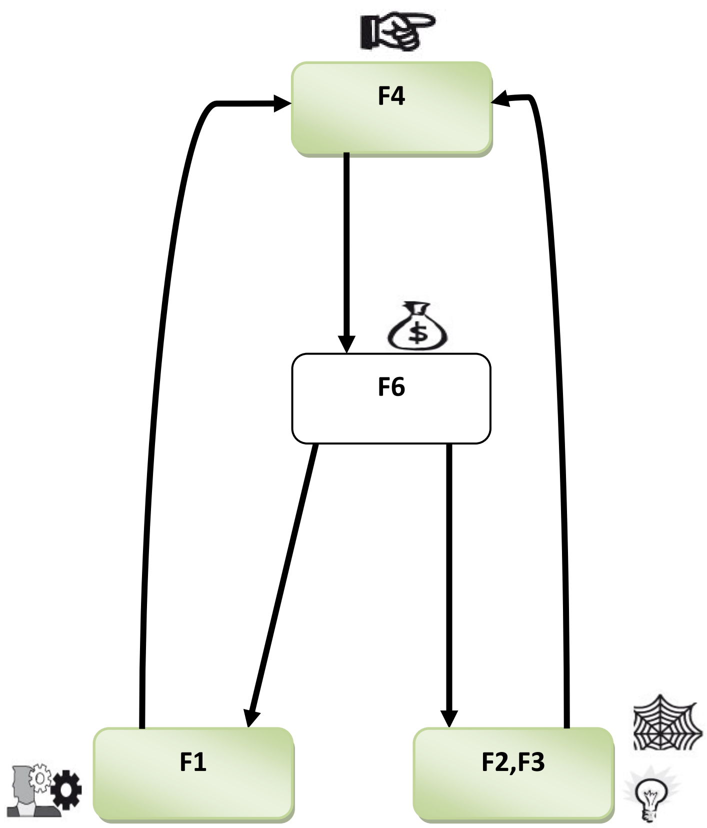


**Figure 5.5: The STP motor for CIGS**

## 5.4 Organic solar cells

### 5.4.1 Function dynamics

The TSIS of organic solar cells started around 1992 with research at ECN. This was with Dye sensitized cells [F2]. Regarding the promising possibilities (low price, abundant material) [F4] with the technology many universities started to do research on the topic [F2]. Organic solar cells encompass two technologies: Dye sensitized cells and polymer cells. ECN started doing research on polymer cells around 1998 [F2] and gradually dropped the research on Dye sensitized cells because of slow and disappointing results. Polymer cells is the technology on which most research is done. This becomes clear by reading the paragraph of Function 2. Also, Function 3 describes collaborations mainly on polymer cells [F3]. This is mainly because this technology can profit from developments in the field of polymer electronics [F4]. The research done is mainly academic and in research institutes; and therefore financed by the government [F6]. There is a lot of collaboration between research institutes and universities and information sharing is open [F3]. This is because there is still a lot to be discovered. In the Netherlands there is no entrepreneurial activity. This is mainly because results have not been staggering so far [-F4] → [-F1]. Foreign companies have started production for small electronic applications. When successful, these can improve the expectations and willingness to invest [F4]. Many applications are possible [F4] but the technology is still too expensive and instable to be applied in these applications.

### 5.4.2 Identified motors of innovation

The possibilities with organic cell technologies make it promising [F4]. This led to mainly academic research [F2] financed by the government [F6]. There is also a lot of information sharing [F3]. Entrepreneurial activity is absent and so are lobbying activities. The lobbying has already been done for the other technologies; and organic solar cell technologies are only following up on that. This gave the following dynamics [F4] → [F6] → [F2],[F3]. This is characteristic for the Science and technology push motor. A STP motor with total absence, so far, of entrepreneurial activity. Philips is for example cooperating in several researches on polymer cells. But no products have been demonstrated so far. Therefore [F1] is not part of the feedback loop (yet) of figure 5.6.

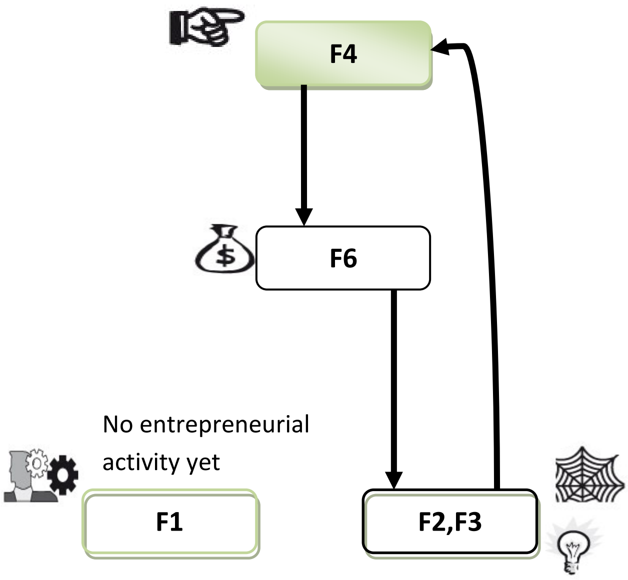


**Figure 5.6: STP motor of organic solar cell technologies**

## 5.5 CdTe

This technology has the disadvantage of containing material that can be toxic in some combinations. CdTe is prohibited when used in combination with certain materials [-F4]. Even though internationally this technology is successful, there is no research done on this technology [-F2,-F3] and no companies are active in it [-F1]. Only Smit Ovens that produces parts of the production processes for foreign companies. Summing up, the bad image of the technology and the fact that it is forbidden to use, blocked all activities regarding this technology [-F4] →[-F1,-F2,-F3,-F6, -F5]. So there has never really been a TSIS. The motors of decline are depicted in Figure 5.7.

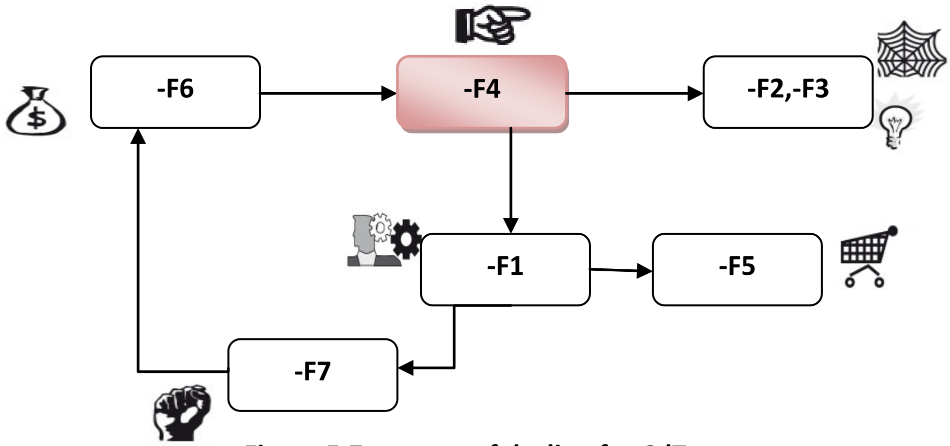


**Figure 5.7: motors of decline for CdTe**

## 5.6 Motors of innovation regarding the total PV TSIS

The Dutch TSIS for PV started with the Science and technology push motors for c-Si and thin film silicon technologies. C-Si was the first technology to be investigated on a small scale. When this research was broadened during the seventies, so was research on thin film technologies. This was because c-Si was quite energy intensive and expensive to produce. Thin film silicon which would need less material was therefore considered the ultimate successor. CI(G)S technologies were also investigated at the time but on a far smaller scale.

All technologies have shown dynamics of a science and technology push motor. The science and technology push motor of c-Si has evolved into an Entrepreneurial motor due to an increase in demonstration projects and confidence from the user side. However in the third period described in paragraph 5.1.1, this entrepreneurial motor crumbled off back towards a science and technology push motor were research and networks between researchers is strong but entrepreneurial activity is weak. Weak, in the sense of selling actual panels to end users.

There exist three types of entrepreneurs:

- The panel and cell manufacturers: these are almost totally focused on the export market and their connection to the home market is weak. Because of the fast developments in the international market, they showed some troubles over the years.

- The panel distributors and installers: These are the link to customers. However, they are mostly disconnected from Dutch researchers and manufacturers. This can be noticed due to the high export of manufacturing companies and the high import of foreign panels by the distributors.

- The machine manufacturers: They are the only entrepreneurs with a clear increase in sales. But they are also mostly focused on export since there is not much production in the Netherlands. They do benefit from the knowledge acquired in the Netherlands and that shows in their market shares.

Shell Solar was for a long time the only cell and panel manufacturer. They collaborated a lot on both research and demonstrations projects involving also project developers. Shell Solar apparently also had the power to convince the government to fund the expensive demonstration projects. Therefore (1985-2003) can be seen as the period where the Entrepreneurial motor emerged from the Science and technology push motor. When Shell Solar left the Netherlands and Solland took the cell manufacturing in the Netherlands while Ubbink Solar Modules was making panels, entrepreneurial activity was mostly focused on export. Because so far there has only been one cell manufacturer in the Netherlands, machine manufacturers were also focusing on foreign markets. These are typically incumbent firms that found possibilities for PV with their expertise, mainly in the semiconductor business. This focus on export and the fact that PV was actually a diversification perhaps made lobby activities from these companies almost non-existent.

Going back to the definition of TSIS 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). The entrepreneurial activity in the Netherlands is mostly concerned with technology (knowledge) generation. This holds for cell manufacturers (actually only Solland Solar) and the machine manufacturers. Their contribution to the TSIS in terms of diffusion of PV in the Netherlands is insignificant. Panel distributors and installers who are in direct contact with the end-users also seem not to contribute to diffusion. Their lobby activities are not strong enough to influence the actions of the government. They are represented by Holland Solar, but this latter also did not arrive to convince the government to implement a stable subsidy scheme. This, while subsidies are the only way to move end-users to buy PV systems which are quite expensive at the moment. This shows from the additionally installed capacity each year, where the years known for having subsidies showed significant increases in installed capacity.

The overall PV TSIS is following the development of the TSIS of c-Si. This is because c-Si is the most mature technology and the other technologies do not have producers in the Netherlands. The market is also dominated by this technology because of its higher efficiency and better price/performance characteristics. So any development in the market and regulations so far has been around c-Si. Most PV technologies have so far only shown dynamics of STP motors. C-Si has gone from STP to a entrepreneurial motor and back to a STP motor as can be seen in figure 5.1, 5.2 and 5.3.

The total TSIS for PV is actually a combination of all TSIS’s. This means that the TSIS for PV in the Netherlands is broadened by the TSIS of each technology. That means more actors that look to develop and diffuse the technologies. All these actors, when working together, can form a strong front to lobby for PV in the Netherlands [F7]. This could eventually lead to clear regulations which will give entrepreneurs a clear view on the future [F4]. Whether this will happen is uncertain because most of the big companies that could have an influence have been relying on export for years.

# 6. TSIS and competition

This chapter will analyze the competition between the PV technologies. Therefore paragraph 6.1 will first explain what is meant by competition for the case of PV technologies in the Netherlands. Paragraph 6.2 will then analyze the competition. Finally, paragraph 6.3 will evaluate whether using a TSIS approach with Function of Innovation Systems was found suitable to analyze competition between different generations of emerging technologies like the selected PV technologies.

## 6.1 Competition in the case of PV technologies

As explained in chapter 1, PV systems are basically composed of one or more PV panels, inverters and/or batteries. The panels are made out of cells. These cells can be made with different materials and production processes. Therefore, the cells define the difference between the PV technologies. Inverters and batteries are not dependent on which PV technology is used. This means that the PV technologies have exactly the same complementary technologies.

Network effects are also not applicable on PV technologies. Network effects occur when the ownership of the technology provides the owner with more benefits when others acquire the same technology (Katz&Shapiro, 1994). This holds for example for telephones. The more users, the more attractive it becomes to have one and in isolation the technology is useless.

A PV system has a lifetime of about 20 years and the initial investment is relatively high (See appendix B). If a consumer purchased a system and it is fulfilling the energy needs, there is no need to buy a new one once a better, more efficient PV technology comes to the market. The only important aspects when purchasing a PV system (and hence a PV technology) are the price/performance ratios and perhaps esthetic aspects. What kind of PV technology is used is therefore not really interesting for the final user. The choice for a certain technology is therefore presumably made by the distributors and installers of PV systems.

In addition, many PV technologies just entered the market or are still in laboratory phase. This, in combination with the previous remarks, shows that the definition of competition between PV technologies is not a just a battle between firms in attaining the highest amount of users for their products or technologies. The first generation PV technologies consisting of crystalline silicon technologies where assumed to be taken over by the second generation thin film technologies which in turn will be taken over by organic PV technologies. Now it is believed that the technologies will co-exist (Kroon, 2011; International Energy Agency, 2010). So for some reasons the generations were not succeeded by each other. This means that the first generation technologies still have factors they hold on to that keeps the following generations from totally taking over. These factors are not really driven by the demand from the final users, as their requirements are clear and simple (best price/performance ratio), but driven by other factors that will be explored in this chapter.

Suurs, 2009, already pointed out that little research is done on the effect that the availability of different technology generations has on the outcome of innovation trajectories. The problem in this case becomes that *"energy policy is not only a matter of balancing R&D vs. market formation, but also a matter of dividing resources across multiple technological options*" (Suurs, 2009). This means that emerging renewable energy technologies rather compete for the allocation of resources amongst each other. This chapter will consider these resources to be all important factors within the functions of innovation systems. This chapter will try to explore whether a specific technology is blocking other technologies in attaining the needed resources.

## 6.2 Competition analysis

**Function 1: Entrepreneurial activity**

Rivalry regarding this function can be measured by looking at the number and type of entrepreneurs for each technology, their activities and which technology has been used in most demonstration projects. As demonstration projects are treated in more detail in Function 2 under learning by using, this first function will focus on the entrepreneurs and their reactions to the availability of several PV technologies.

The first company (Holecsol) was established in 1982 and produced c-Si cells and panels. The other technologies were back then not produced in the Netherlands. Amorphous silicon was only used in imported consumer products but not produced in the Netherlands. CdTe and CI(G)S were not market ready and organic cells were not invented yet. R&S (former Holecsol) however did perform research on thin film silicon in 1996 (Function 2).

Until 1996 Shell was the only producer and produced c-Si cell and panels after taking over R&S. Shell was involved in many demonstration projects at that time. So the demonstration projects were dominated by c-Si panels. This led, as explained in chapter 4, to many learning processes, technologically but also regulatory.

In 1999, Akzo Nobel tried to enter the market producing flexible amorphous silicon panels, in a joint venture with Shell called Helianthos. Akzo Nobel is a chemical company and was not really involved in the PV industry before that. Both companies decided that thin film silicon PV did not fit within their strategies and sold Helianthos to Nuon in 2006. Shell already left the joint venture in 2004. The inability of Nuon Helianthos to find investors to continue their activities resulted in closing down the company in 2011.

1999 was approximately the time where Shell Solar started to feel the competition from foreign manufacturers of c-Si. The involvement of Shell in Helianthos was probably because they believed that one day thin film silicon would indeed be cheaper. In 2004, looking at the fast increase in c-Si panels installed worldwide they probably abandoned this idea.

In 2003 Shell Solar left the Netherlands for Germany and Solland Solar started selling c-Si cells. Around that time Ubbink Solar started selling c-Si panels. Both are mostly focused on export. In 2010, Solar Modules Nederland started a factory producing c-Si panels as well. The companies have seen some troubles also recently in the case of Solland Solar. This was mainly due to international competition from Asian countries producing c-Si panels and cells as well.

Scheuten solar, which started in 2001, produced c-Si panels in Germany and still is. They also started a CIS pilot line in 2007. The products of Scheuten are still made of c-Si.

Future plans for companies involve a factory for solar grade production which is needed for c-Si ingot production; Supercis, a company which will be involved in CIGS; and RGS industrial for c-Si production.  This indicates that c-Si is still being produced and there more plans to exploit this technology, entrepreneurial activities on amorphous silicon all stopped and CI(G)S are upcoming.

Production of CdTe panels has never taken place. This is due to environmental regulations in the Netherlands and this cannot directly be linked to influence from other technologies. However, the availability of other technologies must form a major blocking mechanism for CdTe. CdTe just has more negative aspects compared to the other technologies. Organic PV is still in the laboratory phase. There are some possible niche markets but no interest from Dutch companies has been shown in it so far.

Machine manufacturers have seen an increase in the demand for the production processes they sell. This increase holds for machines involved in c-Si, CI(G)S and CdTe. Their activities on thin film silicon are decreasing. They are not involved in organic PV.

To conclude, most entrepreneurial activity is taking place for c-Si. Thin film silicon cells, which were regarded as the ultimate successor, did not take over. Companies involved in c-Si were also involved in research on thin film silicon. However they also improved their c-Si technologies and only produced c-Si cells and panels. When cell and panel production was taken over respectively by Solland Solar an Ubbink Solar, research on thin film silicon was stopped being performed by companies involved in c-Si. Only Helianthos was left which actually never really produced thin film silicon on a large scale, and recently it was closed down (2011). CI(G)S are now coming up. There are no signs of this technology to take over c-Si. Scheuten is at the moment producing c-Si panels in Germany and started a pilot plant for CIS since 2006; large scale production of CIS has not taken off yet. Furthermore there are plans for a future company for CIGS. All other future plans are involved in c-Si.

**Function 2: Knowledge development**

The main dimensions of this function are learning by using, learning by searching and learning by doing. Learning by doing and using are strongly connected with the first function of entrepreneurial activity. Therefore some aspects of that function will come back in the competition analysis within this function.

*Learning by using:*

Learning by using especially took place during demonstration projects. The company that was mostly involved in these projects was Shell Solar. Hence, the installed systems contained c-Si panels. Chapter 4 explains in detail what lessons were learned during these projects. The demonstration projects led to the invention of certain regulations that minimized the problems that the owner of a system could face. It also made clear that the best practice is to grant the ownership of the systems to the owners of the house on which the system is placed. Furthermore, technical lessons were for example about the distance between panels to avoid heat accumulation. The most important reason for the demonstration projects was off course to prove the viability and benefits of having a PV system. As became clear in Function 5, people realized the benefits but were not really willing to buy a system without subsidies.

Demonstration projects on houses were done with c-Si panels. Very few demonstrations have been done with amorphous silicon. No records were found for CI(G)S and CdTe, and organic panels are not available yet. Crystalline silicon panels were the first to be marketed and hence the first to be used in demonstration projects. This perhaps blocked the way for demonstration projects with thin film silicon and CI(G)S. Their price/performance ratio is not as high as c-Si and the previous demonstration have shown the possibilities with PV. Especially when used in inflexible panel form, there is no use in demonstrating what has already been shown with c-Si panels. This means that demonstration projects with thin film technologies were few or even absent because everything there is to demonstrate was already demonstrated by c-Si.

Figure 6.1 shows which technology is the most competitive so far regarding number of entrepreneurs and demonstration projects over the years. These two are related because local entrepreneurs are usually involved in demonstration projects. This is proven by the involvement of Shell and other panel manufacturing companies in most demonstration projects.

Figure 6.1 shows that Crystalline silicon technologies have seen most entrepreneurial activity and learning processes by using (demonstration projects). This is followed by thin film silicon technologies (TF-Si) and then CI(G)S cells. CdTe and organic cells have not been involved in entrepreneurial activity or demonstration projects so far.

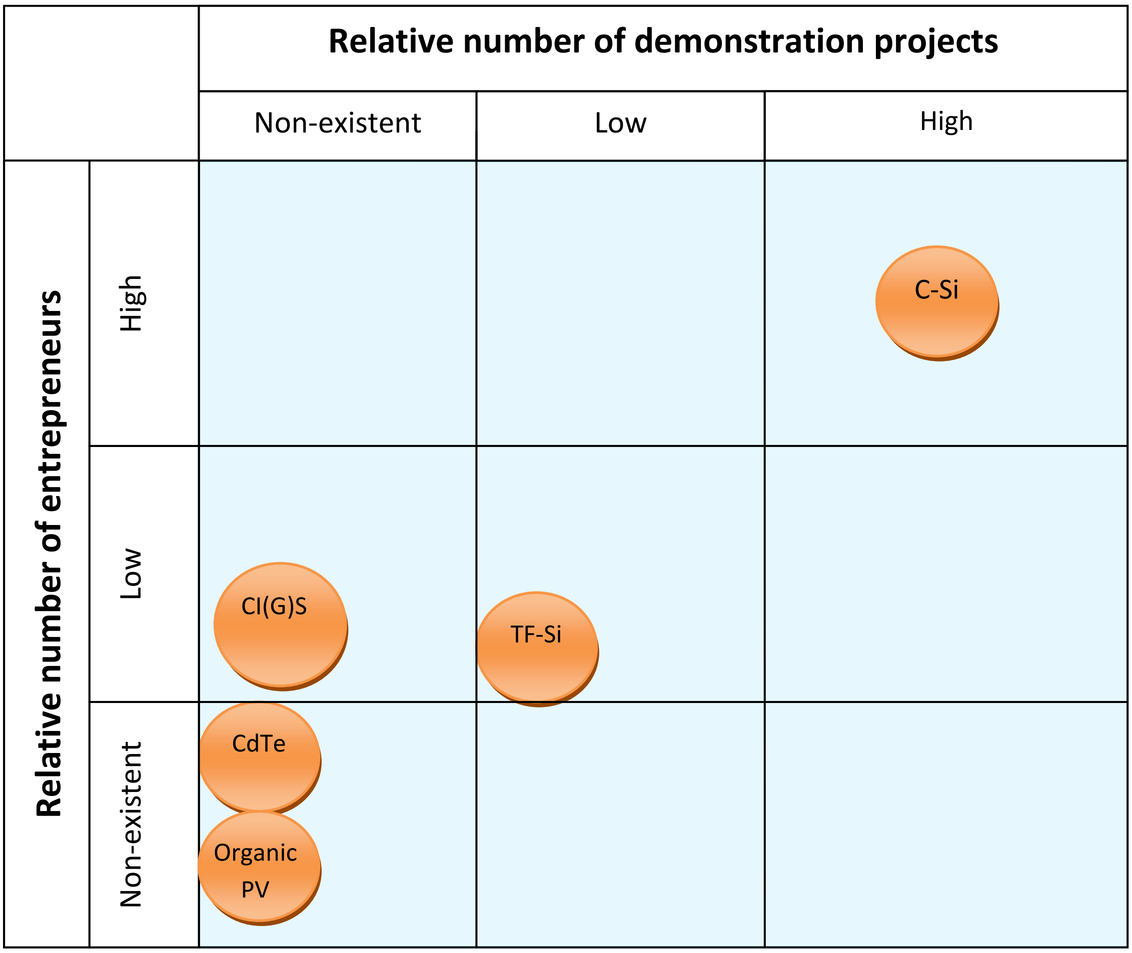


**Figure 6.1: Matrix showing competitiveness regarding number of entrepreneurs and demonstration projects**

*Learning by doing*

Learning by doing can also be explained by Figure 6.1. The technology which enjoys most knowledge due to production is c-Si. This is because it is the only technology with large scale production. Thin film silicon had a pilot plant at Helianthos, but this one is closed down. CIS still has a pilot plant at Scheuten Solar. Further experience on CdTe and CI(G)S is gathered by the machine manufacturers like Smit Ovens. This increases the knowledge on both technologies.

Solland does not have any activities regarding thin film technologies (Dicken, 2011). Scheuten has a pilot line for CIS, but whether this is causing a threat for c-Si within this company is doubtful. The production of c-Si takes place in Germany and they still produce and install c-Si panels all over the world.

Smit Ovens produces part of the production processes for thin film technologies. They are for the greater part dependent on international demand. There is a high demand for CI(G)S and especially CdTe production processes (van der Gugten, 2011). The demand for thin film silicon production processes is decreasing rapidly.

Tempress Systems only focuses on c-Si cell production processes (Scholing, 2011). They are not involved in any thin film technology because c-Si has the highest market share by far and thin film technologies are not really in line with their expertise.

Summing up the given information about learning by doing: Crystalline silicon enjoyed most learning by doing because it is the only technology that had actual producers. The activities of some entrepreneurs with other technologies did not seem to have decreased their activities with c-Si. Significant contributions to learning by doing were made by machine manufacturers. The international demand for their machines did show a preference for mainly c-Si, CI(G)S and CdTe.

*Learning by searching:*

Chapter 4 shows that the beginning of solar cell research in the Netherlands was mostly done at universities. Research on crystalline silicon cells and thin film silicon cells were initiated at almost the same time. Crystalline silicon had the highest efficiency but was too expensive to be commercially attractive. Therefore research on thin film silicon was as popular as research on c-Si. A lot of research was on the characteristics of silicon. This kind of research benefits both technologies. This means that a lot of research is related. Universities working on thin film silicon were usually also involved in research on c-Si. Even though thin film silicon cannot find the way to the market and the only company that was supposed to produce thin film silicon cells was closed, research seems not to be abandoned and still a lot of research is done at universities and institutes. There is also a lot of research on Heterojunction cells (Weeber, 2011). These are cells that combine thin film silicon and c-Si. ECN is involved in this technology and also the University of Utrecht. Besides, Silane, the gas needed to produce thin film silicon can be extracted during the production of solar grade silicon, which makes c-Si and thin film silicon even more connected.

CI(G)S have never really been a big topic in the Dutch solar cell research. CI(G)S were already known to be a an option for PV in the eighties. In 1980, The Chemistry Research Foundation (SON) had only one researcher working on the characteristics of CI(G)S (Verbong, 2001). CI(G)S is now increasingly investigated (Zeman, 2011). TU Eindhoven is increasingly involved in CI(G)S which shows through their participation the project Cigself. The TU Delft did research on the degradation effects of CI(G)S (Zeman, 2011). As the universities involved in CI(G)S did not abandon their previous research topics, there are no signs of CI(G)S taking over research facilities from others technologies. ECN does not do research on CI(G)S. However, they have been involved in the project Cigself for their expertise with cell technologies.

Research on organic cells have been very popular since the early nineties starting with Dye sensitized cells and then with polymer cells. The University of Groningen was involved in organic PV. They were not involved in the other technologies. The other universities that were mentioned earlier were involved. But, whether it can be said that organic PV took the place of any other technology is doubtful. Looking at the TU Delft for example, silicon based technologies and organic technologies are researched at two different faculties. ECN is also involved, but ECN is divided into departments too. Financing also happens usually on a project base. More on that is in Function 6. Organic PV, especially the polymer technology attracted new actors like the Holst Centre and Philips because of their involvement in polymer electronics. So, new people and new capital is involved. When it comes to research, the other technologies are therefore not at stake.

CdTe is not researched at all only perhaps when it comes to production processes at for example Smit ovens. So this technology does not form a threat for the other technologies when it comes to research. The other technologies in their turn block any interest in CdTe because these are expected to be more accepted in the Netherlands. Their performances are good enough in order not to take the risk of using the possibly toxic CdTe.

Figure 6.2 gives an overview of which technologies have been researched in the Netherlands and if the amount of research is affected by competition from other technologies. C-Si and thin films silicon have always been researched, no decrease in interest in researching these technologies can be found (Function 2, paragraph 4.3). Organic PV introduced many new actors to the PV world and the actors involved in organic PV that were involved in other technologies did not seem to abandon their previous research. This can be concluded using the information in paragraphs 4.3 and 4.4. Researchers that are active in a certain technology did not abandon it for OPV and new networks were formed with universities and companies that were not involved in PV before. CI(G)S seem to have lagged behind because of the belief in thin film silicon to take over c-Si. This is gradually changing. Many actors started to help with research on CIGS because of their expertise in other technologies like is the case with ECN (Soppe, 2011). CdTe as explained earlier seems not to be researched because it lacks attractiveness when it comes to safety, efficiency (compared to c-Si and CIGS) and dealing with scarcity of natural resources.

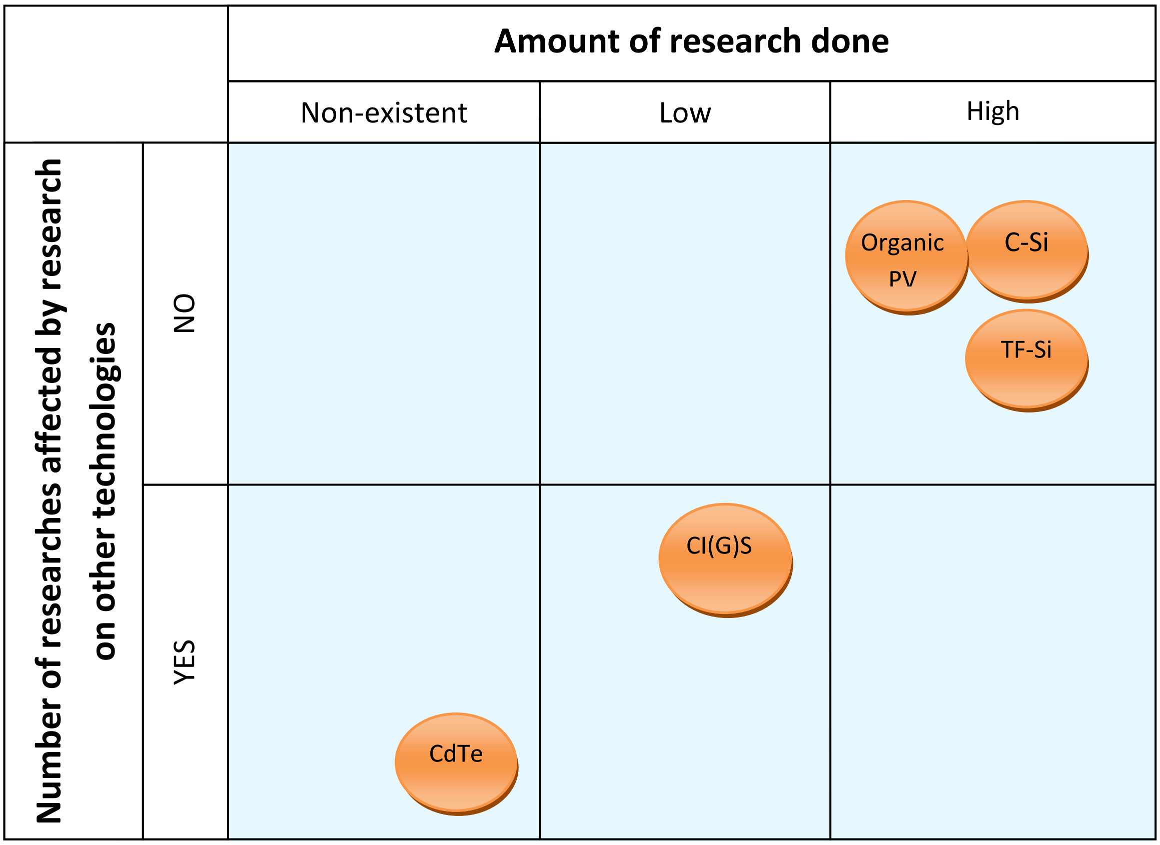


**Figure 6.2: Matrix showing which technologies have been researched most in the Netherlands and if that is influenced by competition from other technologies (Function 2)**

**Function 3: Knowledge diffusion through networks**

Starting with seminars, there is no technology around which more seminars are organized. The seminars are usually a meeting point between actors involved in different technologies (paragraph 4.3). During these seminars, they explain their own activities and discuss national and international developments.

Collaborations on c-Si and thin film silicon were interconnected. R&S, the producer of c-Si worked with the TU Delft on thin film technologies. The TU Eindhoven and TNO, of which especially TNO is known for being involved in thin film technologies, were involved in many collaborations around c-Si (paragraph 4.4). These were the Sunnovation projects. The first Sunnovation project led to a new production process of Silicon nitride using Plasma Enhanced Chemical Vapor Deposition. This was also beneficial for thin film silicon technologies. The TU Eindhoven was also involved in the collaboration in Helianthos together with The Delft University of Technology. Together they improved the technologies used at Helianthos. This again shows that both groups of technologies benefit from each other's developments in the Netherlands.

For CI(G)S there were not so many collaborations so far. But as stated in the previous function, the technology is gaining attention in research. Two considerable collaborations were found. One was around the CIS technology of Scheuten Solar where they cooperated with TNO and OTB-Solar. Each of the parties brought in their expertise for a certain part of the project. The second collaboration is Cigself which is part of Solliance, a collaboration to improve and exploit the position of the Netherlands regarding knowledge on thin film technologies. Many important actors cooperated to start a test production line for CIGS. Each party brought in the part of the production line in which they are specialized. OTB Solar, for example, which is usually involved in the production of antireflective coatings for c-Si is also part of Cigself and they will work on conductive (TCO) layers for the cells (van Gerven, 2010). These layers are made with Silicon Nitride using PEVCD which is also a technology used for thin film silicon and conductive layers for c-Si. ECN which was actually not very involved in CI(G)S also provided their services because of their expertise with other technologies (Soppe, 2011).

Solliance is also involved in organic PV. The other collaborations around organic PV within the Netherlands have been between Universities, research institutes and companies like Philips. What encourages the collaboration is the fact that polymer technologies can benefit from the expertise of companies and research institutes involved in organic electronics. So these actors are not attracted from other PV technologies but organic PV rather extended its network to involve other parties that were before that not so involved in PV before. Within organic PV, the attention of collaborations is going more towards polymer PV instead of Dye sensitized PV. This is because polymers can benefit from developments in polymer electronics. Dye sensitized are more of a stand-alone activity and ECN even dropped researches on this part of organic PV (Kroon,2011).

There are no networks around CdTe. Even Solliance, which is to promote knowledge development for thin film technologies, announced only to be involved in CI(G)S, thin film silicon and organic PV.

What can be noticed around collaborations in the Netherlands is that collaborations involve actors that are active in different fields, PV and non-PV activities. Most collaborations need specific knowledge from each party and therefore these parties are active in different PV technologies. Only CdTe is left out in these collaborations. C-Si and thin film silicon are very connected with a lot of parties involved in both technologies. CIGS also has seen collaborations between parties that are involved in c-Si and thin film silicon. Because Organic PV involves also many companies, research institutes and universities that were not involved in PV before, its network is not really affected by collaborations around other technologies.

Figure 6.3 shows whether the networks of the different technologies were extended or decreased due to the network formation of other technologies. The figure is based on the above mentioned information which is in its turn based on paragraphs 4.3 and 4.4.

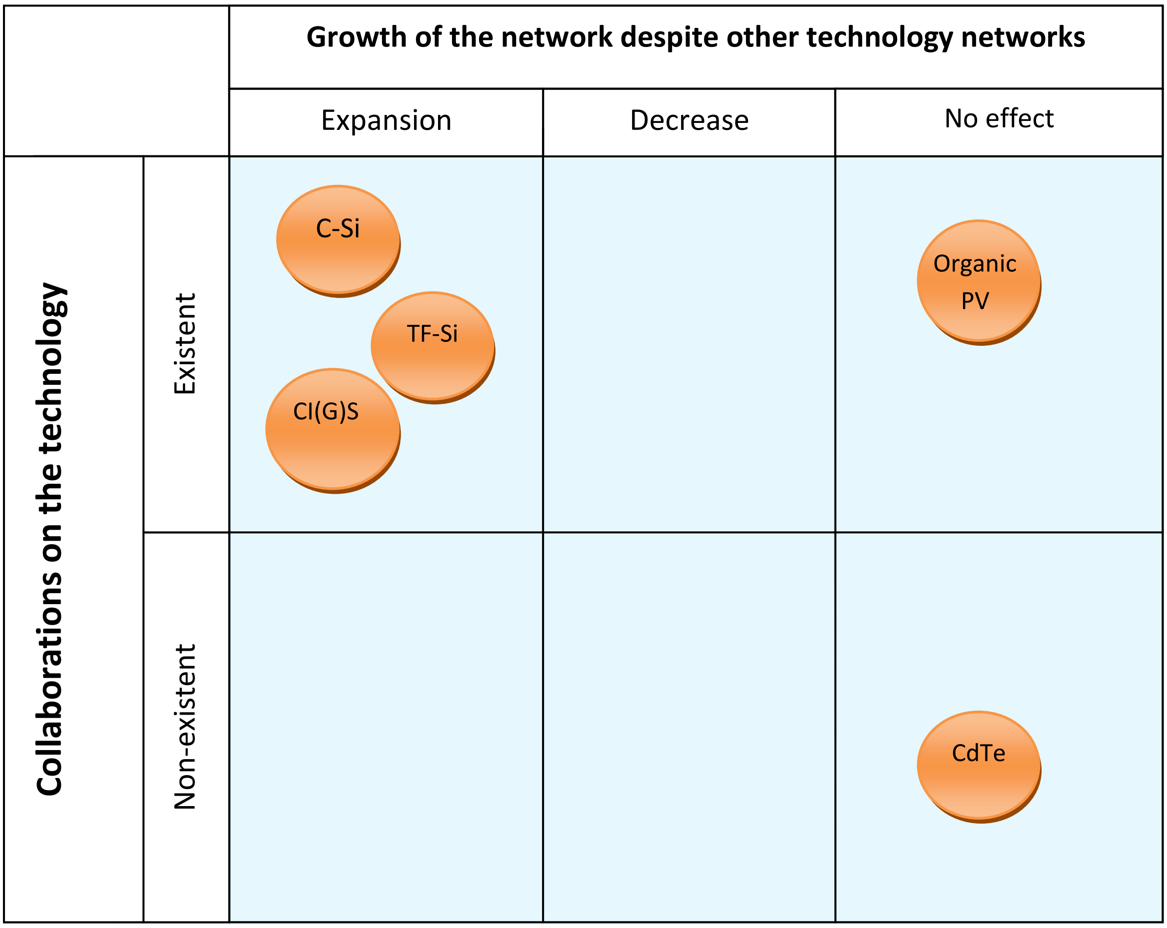


**Figure 6.3: Effect of PV technology networks on each other**

**Function 4: Guidance of the search**

In paragraph 4.5 this function was divided in three parts. One about guidance from the government, the second part was about guidance from companies and the third was about technological expectations.

*Guidance by the government*

The government was especially until the late eighties not very convinced about the possibilities of PV in favor of the Netherlands. This regarded all PV technologies for as far as these have been known. Researches done in order of the government put c-Si forward as the first to be commercially viable and amorphous silicon would be the successor in the future.

Regulations were never in favor of a particular technology or blocking a specific technology. CdTe cells and panels were indirectly forbidden, in a sense that Cadmium was prohibited when combined with certain substances. Tax discounts or subsidies were also not in favor of a particular technology, if any subsidy was provided it would be for PV in general. Many subsidies were even shared between PV and other renewable technologies like wind energy.

*Guidance by companies*

Several initiatives have taken place by companies. Not necessarily companies active in PV cell or panel production but also project developers and utilities. During NOZ-PV 1997-2000 under the PV covenant, they worked together to integrate PV in the built environment. As c-Si was the most efficient and mostly used technology, mostly c-Si panels were installed. This means that the choice went for c-Si just because they were technologically more mature than the other technologies.

*Technological expectations*

Figure 4.5.1 in chapter 4 shows the expectations regarding efficiency of the technologies. C-Si is clearly expected to have the highest efficiency. Thin film silicon was considered the ultimate successor of c-Si for a long time but this gradually changed in the eyes of the actors of the PV industry worldwide. The main cause for this seems to be the difficulty to get the efficiency of thin film technologies above 10%. This problem has been the same for years (Verbong, 2001; Soppe, 2011). CI(G)S on the other hand have seen remarkable increases in efficiency. Also the possibility to print the technology with a roll-to-roll process seems to increase the expectations around this technology. CdTe is not popular in the Netherlands. However, on an international scale it is. CdTe has the highest international market share among thin film technologies. The result of this success for the others (especially thin film technologies) in the Netherlands can be that investors will prefer to put their money in this technology. Helianthos failed to find investors. They looked for investors all over the world but there was no interest. The high expectations regarding CIGS and CdTe internationally perhaps explain this. On the short term these technologies will probably bring higher profits. This, without forgetting the ongoing developments around c-Si which already has the highest cost/performance ratio.

Organic PV are for now not expected to take over the panel market any time soon. Their short term application will be in consumer electronics. This technology, as explained earlier, is also supported by the organic electronics business. Therefore they are sort of protected against the other PV technologies. No investors have shown interest so far in the production processes developed for example at ECN (Kroon, 2011). This is because the benefits of this technology are gained on the long term and because there is no successful product which could function as niche market for the cells.

The main reason to look for thin film technologies was the fact that silicon production is energy intensive. Shortage of silicon was also an issue for a while. This is not the case anymore as the number of silicon producers increased and it is just made out of sand. CIGS contain Indium which is finite and CdTe contain tellurium which is also finite. This is a subject of discussion among actors but at the moment this does not seem to be an issue. However the long term possibilities of scarcity perhaps keep research on thin film silicon going. It uses silicon which is not scarce and there is a possibility to produce the cells at lower energy intensity.

The competition for technological expectations seems to be more between the thin film technologies. With CdTe and CI(G)S having short term benefits but possible problems on the long term, and thin film silicon with no short term benefits but possible advantages in the future.

Figure 6.4 shows which form of guidance has had most influence on the development and diffusion of the technologies and which technologies were mostly affected by guidance regarding the other technologies. As the government was not putting any of the technologies in favor through subsidies or tax support (Paragraph 4.5, 4.6, 4.7), this guidance had little influence on the competition between the technologies. Only CdTe was avoided because of environmental regulations. C-Si was just widely used because it has the best cost/performance ratio. Technological expectations on the other hand were very influential.  As explained earlier, thin film silicon and CI(G)S showed the heaviest reactions due to technological expectations. C-Si is expected to have the highest efficiency for a long time and is showing very little disturbance due to developments in other technologies. Expectations regarding organic PV is high, especially the polymer technology. Even though investors are not really standing in line to invest in production lines, the technology still benefits from developments in the field of organic electronics. Expectations are also high regarding the long term. This shows especially through the amount of research done on the topic (Function 2, paragraph 4.3).

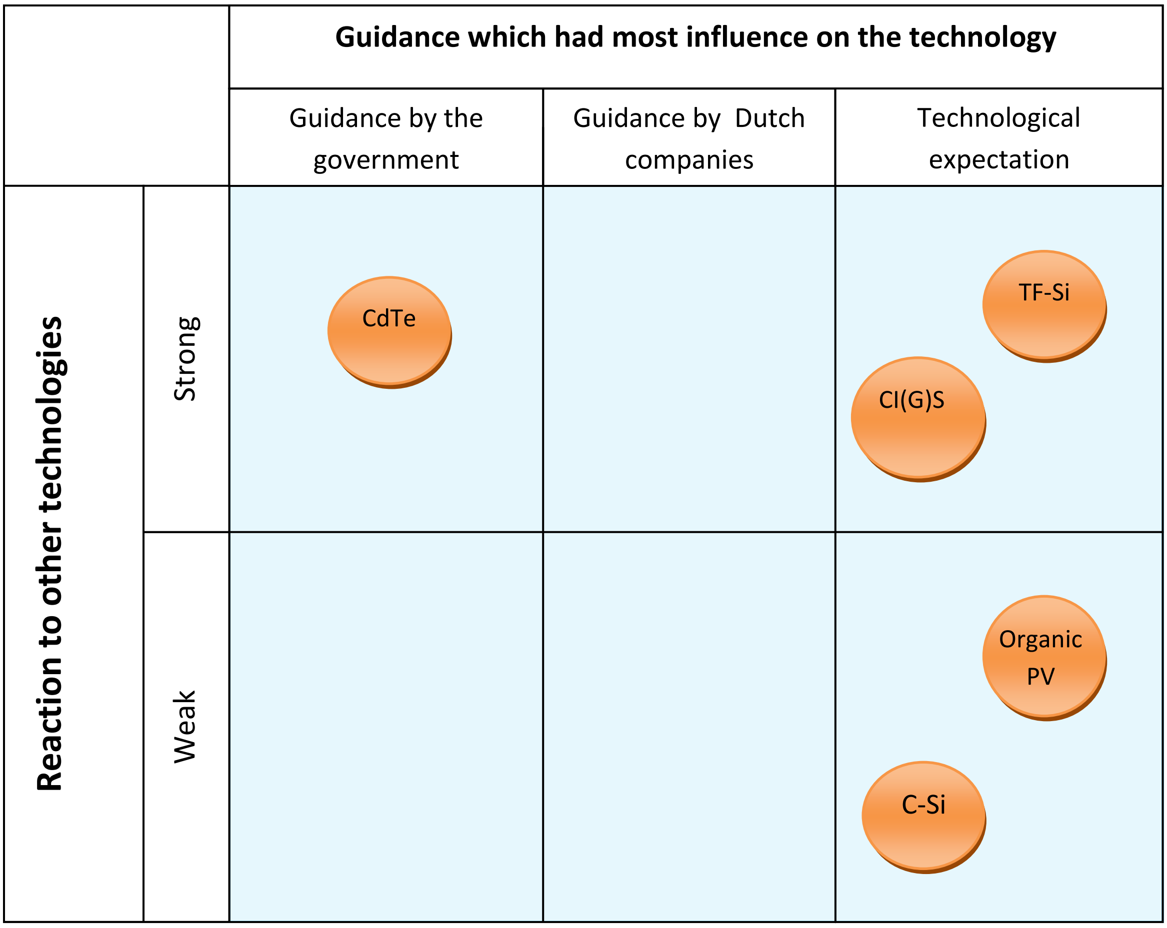


**Figure 6.4: Influence of technologies on each other regarding guidance of the search**

**Function 5: Market formation**

As production in the Netherlands only takes place for c-Si, these technologies dominated the export. Almost all installed panels were also based on c-Si. The increase in demand for PV was not due a certain PV technology but rather because of the possibility to connect PV systems to the grid. As it does not matter which technology is used to connect the system to the grid, this had no influence on the choice for a certain PV technology. C-Si has the highest price/performance ratio and that is why it is mostly applied.

Subsidies and taxes were also not in favor of a certain technology. So these had no influence on competition between the technologies either.

**Function 6: Resource mobilization**

No competition could really be noticed when considering subsidies for research. Research on the different PV technologies was initially (seventies and eighties) financed as fundamental research. Then, NOZ-PV started to finance PV. C-Si technologies received more subsidy then thin film silicon but this was because c-Si needed more applied research because it was more mature. The other thin film technologies were just not that much of an option at that time. The budget for NOZ-PV increased over the years and more demonstration projects were financed. These were of course done with c-Si as explained in previous functions. Subsidies like EET and EOS were not particularly for PV but for more renewable energy technologies and they were project based. EOS is divided into several categories (feasibility studies, short term research, long term research, fundamental research). This means that if an organization wants to start a research they have to hand in a plan and this would be partly subsidized when found useful for a certain category. This is of course dependent on the view of the decision makers regarding a technology, but it is also dependent on how convincing the plans are presented. This means the granting of subsidies depends on the goals of the research and how long it takes for it to show results. There was no distinguishing between c-Si or thin film technologies (AgentschapNL , 2010b).

There are many organizations that support research. Some of them were only discovered during interviews (like M2i, Zeman, 2011). FOM and NWO finance fundamental research. This can be for a particular technology but some researches are beneficial to all. For example “Up and down conversion of photons” where photon energy is adapted to the band gap of the PV technology (Joint Solar Panel, Function 6 paragraph 4.7). Besides, there are also subsidies from provinces. The province of Noord-Brabant invested 28.2 million in the Solliance collaboration in which thin film technologies are the centre of attention (TF-silicon, CI(G)S and Organic PV).

Functions 4 and 5 have already shown that there was no differentiation when it comes to market stimulation subsidies and Tax refunds. C-Si only benefited most from these subsidies because it was a more mature technology with a higher cost/performance The EET and EOS subsidies are granted for projects for which a plan has to be handed in.

When it comes to raw material, the technologies do not really compete for the same natural resources. C-Si uses silicon which is extracted from sand and is abundant. The same holds for thin film silicon for which Silicon nitride gas can even be extracted during the production of solar grade silicon used for c-Si. CI(G)S use Indium and Gallium which is finite and there are threats of scarcity when CI(G)S are produced on a very big scale. CdTe contains Tellurium which is also scarce. Regarding organic PV, scarcity is not an issue and its compounds are totally different from other PV technologies so they do not compete on natural resources.

Table 6.1 summarizes the information above and shows whether there is a competition between the technologies regarding resource mobilization. The table combines information from functions 5 and 6, paragraphs 4.6 and 4.7. Going back to Function 2, there could be a link between the advantage that some technologies have when it comes to raw material. C-Si, TF-Si and organic PV are mostly researched in the Netherlands. These are the technologies with the least risks regarding raw material availability. However an international interest shift towards CI(G)S made the Dutch look into this technology as well.

| | Priority in research subsidies | Priority in market stimulation | Advantage regarding raw material |
|---|---|---|---|
| **c-SI** | | | x |
| **Thin film silicon** | | | x |
| **CI(G)S** | | | |
| **Organic PV** | | | x |
| **CdTe** | | | |
| **None of the technologies** | x | x | |

**Table 6.1: Competition on resources**

**Function 7: creation of legitimacy**

As discussed in Chapter 4, there is no strong coalition that promotes PV in the Netherlands. There is also no group that is trying to lobby for a certain PV technology. Most problems arise out of an unstable subsidy scheme and all technologies suffer from that. Lobbying for a certain PV technology to lock out the others would only arise when PV is totally accepted and becomes part of the regime. Then, issues like scarce materials in some technologies could lead to lobbying against them. Even then, lobbying would not be necessary because scarcity would immediately reflect in the price of the technologies.

## 6.3 Evaluation of the competition analysis

Considering the analysis per function of innovation system in the previous paragraph, there are a couple of conclusions. C-Si technology is the least affected the existence of other technologies. This technology has always had the best cost/performance ratio. This made this technology the first and mostly used, also when it comes to demonstration projects. C-Si therefore had the advantage of being first to market. C-Si therefore also set the standard to which the other technologies have to comply at least to be attractive. C-Si producers were mainly influenced by international competition, also mainly from c-Si technology producers in Asia.

The technologies are not really competing when it comes to research. Universities and institutes did not drop technologies they were working on previously when they started with new technologies. In many cases developments in one technology are beneficial to others, especially in the case of c-Si and thin film silicon. Fundamental research tackles problems that have to deal with many technologies. The fact that knowledge around certain technologies helped to develop others can also be concluded by considering the Cigself project around CI(G)S. All the actors involved in this project have been involved in other technologies and each of them brings certain competencies from which the project can profit.

There were technologies that took a long time to be interesting for research (CIGS) and some were not researched at all (CdTe). This had to do with expectations, problems of scarcity or toxicity.

Most of the “tensions” or signs of rivalry can be linked back to technological expectations of Function 4. C-Si technologies are expected to have the highest efficiency. The production processes are meanwhile becoming more standardized and efficient. As c-Si technologies already have the best cost/performance ratio, they have a lead on the other technologies.

Thin film silicon technologies were expected to be the successor of c-Si technologies. Therefore they were getting a lot of attention in research. CI(G)S and CdTe were at first not that attractive because of the scarcity of the materials and toxicity in the case of CdTe. When on an international scale thin film silicon technologies were not seeing much new developments and CI(G)S and CdTe were, research in the Netherlands started to take off. This is especially regarding CI(G)S. CdTe is still not interesting. The fast developments of CI(G)S and CdTe, in combination with the performance and the developments of c-Si, seem to have caused a loss of interest in thin film silicon when it comes to investors. This led to the closing of the only company involved in thin film silicon. Technological expectations are also what make researchers very interested in organic PV. The expected cheap production processes makes this technology very attractive. But because the application for panels will still take a long time, investors in the Netherlands are not yet willing to invest in production lines.

The technological expectations seem to have played a bigger role when it comes to competition than guidance by the government or companies. The government did not express preference for any of the technologies. Companies (other than producers of cells and panels) just applied the technology with the best cost/performance ratio and that was c-Si.

Function 5 could not be used to analyze competition between the PV technologies. Subsidies did not distinguish between them. And, there were no specific niche markets in which one technology had a clear advantage over the others.

Function 6 did not really show a competition between the technologies. Only the availability of natural resources could give an indication. But that is again strongly connected to technological expectations. Since the amount of material used in the production process can give an indication of how important scarcity of the material is.

Function 7 also did not contribute to the analysis of the competition between the technologies. All PV technologies face the same problem at the moment which has to do with the fact that subsidies are needed to convince most people into using them. The government also does not really show a preference which makes lobbying for one specific technology useless.

Summing up all the previous remarks, the rivalry between the technologies in the Netherlands was mostly influenced by international factors. The technologies are developed and produced all over the world these developments, and the success of certain producers, have influence on the decisions of actors in the Netherlands regarding research and investments. Companies in the Netherlands are also dependent on foreign investors who also consider international developments and offers.

# 7. Conclusions

The research aimed at defining the factors that boosted or hampered the development and diffusion of PV technologies in the Netherlands; and how that has reflected on the competition between the technologies. The main research question was therefore:

"*What factors of the Innovation System of PV technologies boost or hamper their development and diffusion in the Netherlands and how did that affect the competition between them?"*

To answer this main research question, several sub questions were formulated. The conclusions will be given according to these questions:

*"What are the available PV technologies that are being used and developed in the Netherlands?"*

The technologies that were chosen are Crystalline silicon solar cells, Thin film silicon solar cells, Copper Indium (Gallium) Diselinide or CI(G)S solar cells, Cadmium Telluride (CdTe) solar cells and Organic solar cells. These are the technologies that are being used or are expected to be used in terrestrial power supply in the Netherlands.

*"What are the available theoretical frameworks to analyze the development and diffusion of technologies?"*

In the literature on innovation systems and technological transitions, several models were mentioned which could be used in the analysis. Based on several selection criteria, a couple of models were considered. The models that have been investigated were Porters Diamond Model, The Multilevel Model, Large technical systems, National Systems of Innovation, Sectoral Systems of innovation; and Technology Specific Innovation Systems (TSIS).

*"Which framework is most suitable to analyze the development and diffusion in the case of PV technologies in the Netherlands?"*

The Technology Specific Innovation System was found to be the most suitable among the considered models to answer the main research question. This was because this model, using Functions of Innovation Systems FIS, complied to most of the selection criteria. These criteria were that the model should be technology specific as is to be used for the analysis of PV technologies; the model should analyze how the technology is diffused; R&D should be an important aspect as the technologies are still in development; because of the ongoing and past developments the model should be able to analyze the situation on a large time span; the model should consider multi-actors environments and it should analyze the interaction between the actors (dynamic analysis); the technology is not only dependent on actors but also on other factors on which actors have no influence, this should also be considered in the used model. The Technology Specific Innovation System was analyzed for each of the PV technologies.

*"Using the chosen framework, how has the development and diffusion of each technology evolved in case of the Netherlands since 1974?"*

***Function 1: Entrepreneurial activity***

The only technology that has been produced in the Netherlands was *c-Si*. The first company established was already focused on the export market because the Dutch government was not sure it would be viable in the Netherlands. Unstable subsidy schemes made the Dutch market unstable as people were waiting for better subsidies or waiting for lower panel prices. This kept the Dutch companies focused on export.

Dutch companies involved in the production *c-Si* are now faced with a strong competition from Asian countries producing the same technology. This is the main cause for the troubles they have seen the last couple of years. Instabilities are therefore not caused by competition from thin film technologies.

*Thin film silicon* has never been produced in the Netherlands, only a pilot factory was established, Helianthos. The company had troubles finding investors and was therefore closed down. They did participate in research projects with universities and research institutes.

*CI(G)S* were not produced in the Netherlands. There is only a pilot factory for CIS by Scheuten Solar. They did not start large scale production of the technology yet. They do have a *c-Si* factory in Germany which is still active and there are no signs of *CIS* taking over.

Other technologies like *CdTe* and *Organic PV* have not seen any entrepreneurial activity in the Netherlands.

Machine manufacturing companies were very important in the Dutch TSIS. Not really when it comes to diffusion of the technology but because they contribute to knowledge development. Their customers are also mostly abroad. The demand for their products has been rising very fast because of the production increase mainly in Asia. The technologies in which they are involved are c-Si, thin film silicon, CI(G)S and CdTe. Mainly the demand for *c-Si*, *CI(G)S* and *CdTe* has risen. The demand for *thin film silicon* is decreasing.

***Function 2: Knowledge development***

*C-Si* is the technology that has been researched most in the Netherlands. This was because this technology had the best cost/performance ratio and was first to be market ready. The high energy costs to produce c-Si called for research on thinner technologies. *Thin film silicon* was therefore also a very popular research topic in the Netherlands. Later on the positive expectations regarding Organic PV made this technology also a popular research topic at universities and research institutes.

Especially *polymer organic cells* gained attention because it could benefit from developments in the organic electronics sector.

*CdTe* was never really a subject of research in the Netherlands. The fact that this technology used scarce and toxic materials made this technology uninteresting for Dutch researchers.

*CI(G)S* were not very popular either because of scarcity of the used materials. This would make the technology not totally sustainable. *Thin film silicon* which is actually made out of sand was much more interesting. However, the international slow developments regarding thin film silicon and the positive results regarding CI(G)S made this technology increasingly interesting for the Dutch researchers and companies. Especially machine manufacturers were interested in the doing research on the technology.

***Function 3: Knowledge diffusion through networks***

Information sharing between actors in the Dutch PV TSIS is open. This is because there is a lot to be developed and information needs to be shared to make progresses. Seminars that have been held were mostly for PV in general where every technology is considered.

Most collaborations have been around *c-Si*. When looking at *thin film silicon* especially Helianthos is considered. Helianthos was the only company involved in this technology.

There have been many collaborations between research institutes and universities regarding organic cells, especially polymer cells. This is because polymer cells benefit also from developments in the polymer electronics sector, and the other way around.

Collaborations are now forming around *CI(G)S* because of the international developments, for example with the project Cigself. For *CdTe* there are no collaborations.

***Function 4: Guidance of the search***

The Dutch government was not convinced of the usefulness of PV in the Netherlands. Until 1986, the government did not express support for PV. In 1986, regarding international developments, the government decided to support research and focus mainly on developing countries where there could be a profitable market.

*Crystalline silicon* and *thin film silicon* were mentioned a lot but this was because these two were the technologies that were mostly researched in the Netherlands.

Around 1994, subsidies to stimulate the market were introduced. These were however not specifically for PV but also for wind energy and other technologies. The subsidies also did not distinguish between the different PV technologies. The EPR subsidy resulted in a staggering increase in installed PV systems. This was because this subsidy covered a very big part of the costs directly. This subsidy was cancelled and replaced by MEP and later on SDE with which the production of sustainable energy was subsidized. This way only the actually produced green energy was subsidized. The SDE was cancelled and replaced in 2011 by the SDE+ which only considered big systems (>15KWp). Because of the many changing subsidy plans, customers were hesitating to buy systems and did not believe they would get a stable subsidy when acquiring a PV system.

Companies also tried to stimulate the image of PV. Utilities provided subsidies to purchase systems and herewith boost their green image. These subsidies were quickly cancelled after cancellation of the EPR subsidy.

Collaboration between the government and companies like project developers boosted the guidance during the PV covenant. The ending of the PV-covenant in 2000 and the exclusion of project developers from the EPR subsidy ended this positive guidance from companies.

Technological expectations and international developments kept the research on the technologies going. *C-Si* are expected to have the highest efficiencies and *CI(G)S* are upcoming. There are high expectations for organic PV but not on the short term. These international expectation show strong dynamics when it comes to research and the market.

***Function 5: Market formation***

Subsidies to stimulate the market did not distinguish between the technologies. *C-Si* technologies were mostly used because they have the best cost/performance ratio.

The demand only shows fast rises when there are subsidies. This is because PV systems are still quite expensive. Especially the EPR led to a fast rise because the costs acquired system would be partially refunded. The SDE also showed a rise but slower. This is because the subsidy amount per KWh is adjustable and customers only get paid for what they actually produce so the pay-back time is longer.

A lot of systems have been installed without SDE. This is because there are also subsidies from municipalities.

The unstable market made companies focus on export. Between 2004 and 2006 there was more import than export. This indicates that most of the installed systems in the Netherlands are import products. This means that the local market is disconnected from the local producers of cells and panels.

*C-Si* panels were installed most in the Netherlands. First because they were the only panels used in demonstration projects in which Dutch producers were involved. Later on because these technologies have the best cost/performance ratio which is important regarding the fact that most systems are installed on rooftops which are small spaces. There are no niche markets in which the thin film technologies could really stand out.

**Function 6: Resource mobilization**

Market stimulation subsidies did not distinguish between the technologies. All PV systems could get a subsidy. Subsidies were even for several sustainable energy technologies.

The research subsidies of NOZ-PV spent more on c-Si. This was mainly because these technologies were more advanced and also more applied research could be done on it. Thin film silicon was the second and new concepts mainly consisting of organic PV were also financed.

Next to NOZ there were and still are subsidies from FOM and NWO. These are mostly focused on fundamental research including also organic PV. Some fundamental research can be beneficial to several technologies.

NOZ-PV was ended and the EET subsidy came. Later on there was the EOS subsidy. These subsidies are project based. Researchers could apply for research subsidy which would be granted based on their plan's viability. There only selection criteria was that the technology should be around c-Si or thin film technologies. No thin film technologies are excluded from research subsidy. EOS is also divded in different categories ranging from fundamental research to industrial research.

Employment was highest in c-Si but these are the only technologies which are actually produced.

CI(G)S and CdTe have limited natural resources. C-Si, thin film silicon and Organic PV do not have this problem. Solar grade silicon is however not produced in the Netherlands. This makes Dutch producers dependent on foreign production. The unlimited availability of natural resources for C-Si, thin film silicon and OPV made Dutch researchers more interested in these technologies than others.

***<u>Function 7: Creation of legitimacy</u>***

Lobbying was not done for a specific technology. Lobbying was done by researchers to bring PV to the attention in order to get subsidies for research. International organizations also played a role in convincing the government to support PV.

Dutch companies never formed a strong lobbying front. This was because there are only a few producers focused on the export. Machine manufacturers are also focused on export and are not dependent on the Dutch market. Installers and distributors are many small companies that mainly import their products and are therefore disconnected from producers and machine manufacturers.

***<u>Motors of innovation</u>***

Most technologies only showed signs of motors of science and technology push. This entails that a lot of research was done on the technologies but entrepreneurial activity was weak or even absent. This was concluded by analyzing the interaction between the seven Functions of Innovation. Crystalline silicon solar cells were the only solar cells to have experienced an entrepreneurial motor. This entrepreneurial motor was not strong enough and fell back to a science and technology push motor. The reason for this was the unstable attitude of the government and the unstable subsidy scheme. This unstable subsidy scheme made consumers hesitating to buy a PV system or waiting for better subsidies. As a result, the cell and panel producing companies were focused on export. On the other hand distributers and installers of panels were not in close contact with producers and imported many panels from abroad. This led to a disconnection between the two entrepreneur types. This again led to less lobbying power and the subsidy scheme always stayed unclear and unstable. Crystalline silicon is still the mostly sold PV technology in the Netherlands.

The companies making cell and panels did however contribute to knowledge development and network expansions. Also machine manufacturers contributed to this knowledge and network expansion. This resulted in STP motors with a very strong connection, still, between entrepreneurs and the research world.

*"Is the chosen framework suitable to analyze the competition between technologies that serve the same purpose?"*

The competition between the PV technologies seemed to be caused principally by international factors and by time of introduction. Time of introduction played a considerable role when it comes to the amount of demonstration projects done. Because c-Si technologies were the first to be produced, these technologies were used most by far. All important aspects have already been shown and learned with c-Si. The benefits and problems became clear and there is no use of showing this again with another technology.

Technological expectations based on international developments per technology had most influence. This is probably because investors base their decision on these international developments. This had influence especially on entrepreneurial activity. It seemed that the role of the government was insignificant in assessing the competition between the technologies. There was no particular preference for a certain technology which would be expressed through subsidies or tax reductions. Function 5, in which protection of niche markets is central (mainly by the government), did not show a competitive advantage for a specific technology.

Function 6, Resource mobilization, also did not show preference for a certain technology when it comes to subsidies for research or market stimulation. Availability of natural resources, which is part of this function, is actually an international matter. This indicator however showed a couple of reasons why certain technologies stay interesting for research.

Function 7 also could not be used because the technologies are still emerging and developing. Actors can get more benefit out of working together even if they are in favor of different PV technologies. Influential actors like the government are not really distinguishing between the technologies.

This means that some functions of FIS were not relevant to analyze the competition between PV technologies in the Netherlands. Mainly internationally defined factors were relevant for the analysis but these were spread amongst the functions making their influence less noticed. These international factors need to be considered separately. This will be proposed in the next chapter, introducing an $8^{th}$ function dealing with international factors.

*"What factors of the Innovation System of PV technologies boost or hamper their development and diffusion in the Netherlands and how did that affect the competition between them?"*

The government played a big role in the TSIS of each of the PV technologies. The role of the government was important for the stimulation of research on PV in the Netherlands. The government wanted to keep up with international developments. So stimulation was not for local use of PV. The government did not really distinguish between the technologies leaving the decision to choose the technology to be explored to the researchers.

The focus of research in the Netherlands was mainly c-Si and thin film silicon. Later on at the beginning of the nineties, organic PV gained attention because technological expectations were high internationally, but on the long term.

The government also did not distinguish between the PV technologies when it comes to market stimulation. Each PV system could get a subsidy. The government did therefore not play a role in the competition between the different technologies when it comes to research or the market development. Subsidies for market stimulation were not stable, this made the local market unstable and entrepreneurs were focused on export.

C-Si had the advantage of being the first to be introduced to the market because it had a better cost/performance ratio. The first producers in the Netherlands were also making c-Si cells and panels. This made this technology the first and mostly demonstrated technology. Having shown the possibilities with PV using c-Si made demonstrations with other technologies later on less needed.

Entrepreneurs strengthened and stimulated knowledge development and diffusion in the Netherlands. Believing that thin film silicon would take over one day, made them also involved in research on that technology. This belief was shared by companies and researchers worldwide.

Organic PV was researched by new parties. Universities and research institutes that were not involved in PV before; and separate departments at research institutes and universities that were already involved in PV. This technology therefore created a TSIS with many new actors not active in the other technologies. This stimulated knowledge development. Entrepreneurial activity is still lacking because there are no successful short term applications yet.

CI(G)S never received much attention in the Netherlands. This was mainly because CI(G)S used scarce materials. CdTe had the same problem. These technologies recently became very successful internationally. This especially made machine manufacturers active with these technologies because there was a rise in international demand for production processes that these machine manufacturers were specialized in.

These international developments made actors in the Dutch PV TSIS more interested in CI(G)S and started to do more research. This did not mean they quit activities in other technologies they were involved in.

These international success of CI(G)S and CdTe, combined with the success of c-Si made investors lose interest in thin film silicon which has seen internationally slow results. This became an obstacle for entrepreneurial activity regarding production of thin film silicon technologies. Thin film silicon is still a popular topic of research for the actors that were involved in it before. This is probably because CI(G)S and CdTe use scarce materials which could form an issue one day.

The focus on export of c-Si manufacturers, the strong position of machine manufacturers in the world market and vast knowledge of universities and research institutes in the Netherlands made the TSIS of each technology more focused on Knowledge development and diffusion. Diffusion of the technologies within the Netherlands is lacking.

The panels available in the Netherlands are now mainly imported by distributors. The local market is therefore disconnected from producers and manufacturers. These imported panels are mainly c-Si because worldwide these panels show better cost/performance ratios. Mainly panels made in Asia are cheap and cause a threat to Dutch producers also on the international market.

As there are no aspects within the Netherlands on which the technologies compete. Their competition is mostly defined by international factors. These are factors like international technological expectations; international demand; investors from abroad; and availability and price of natural resources. These factors and others are proposed to be accumulated in a separate function in the next chapter (Discussion and recommendations).

# 8. Discussion and recommendations

## 8.1 Theory recommendations

### *8.1.1 Summing international factors in a separate function*

As described in chapter 6, the factors that have most influence on the “competition” between the technologies are defined by international factors. Many of these international factors are embedded within different functions of the FIS framework as several indicators. What became clear during the analysis of the motors of innovation in chapter 5, is that indicators within the same function are not equally important. This means that one indicator can overrule several others making them unnoticed when deriving a motor of innovation. Indicators can also have contradictory results. For example, technological expectations are part of Function 4, Guidance of the search. Also the expectations of the government are in the same function. The government in the case of PV is not really distinguishing between the technologies. Technological expectations are made by professionals or scientists and they know the differences between the technologies well. Suppose the government is providing subsidies for PV in general, but professionals are not very positive about one specific PV technology. Then, there are two contradicting indicators both within the same function.

The international community can be positive about a technology while the government is not. These are again two indicators that would be used in Function 4. These are two very contradicting indicators and with different results.

In Function 6 (Resource mobilization), the availability of natural resources is used as an indicator. This could be relevant for this function if the country involved has a closed economy and is not influenced by international demand and pricing. Or, if one wants to analyze which technology could be lucrative looking at the national natural resources. This is then more related to the analysis of a national system of innovation. Availability of natural resources therefore does not seem to belong in Function 6 when considering TSIS.

Availability of natural resources is an international matter. The government or any other actor within the Dutch TSIS does have the power to determine the price of these resources. In the case of c-Si for example, the Netherlands does not have any producers of solar grade silicon. There are plans for a factory to produce it, however, their clients will not only be situated in the Netherlands. This means that they have to adapt their prices to the international standard. And even if they only had clients in the Netherlands, they still have to adapt their prices because Dutch companies can get the product elsewhere. In conclusion, availability of natural resources is an independent factor and it cannot be included in Function 6 which is mostly the result of other functions when looking at motor of innovation. Else, the idea of cumulative causation where one function leads to another would be used the wrong way.

Summarizing what has been stated above, all factors that are dependent on international circumstances cannot be embedded in the seven functions defined by FIS as used in this thesis. International factors should be accumulated in a separate function. This function in its turn influences the other 7 functions, not the other way around, or not easily. When considering the Multilevel Approach, this additional function would be part of the Landscape.

Figure 8.1 shows the additional function and its relation to the other already existing functions. This Function 8 could be called International drivers. This function has influence on guidance of the search [F4] because governments usually do not want to lag behind other countries, certainly when it comes to research. This showed in the support for PV research even though the government was not convinced of its usefulness in the Netherlands. Technological expectations and other factors create opportunities for entrepreneurs [F1]. These opportunities are not necessarily in the entrepreneurs' country of origin. International developments point out important research topics [F2][F3] and create niche markets [F5]. Investors [F6] also base their decisions on international factors.

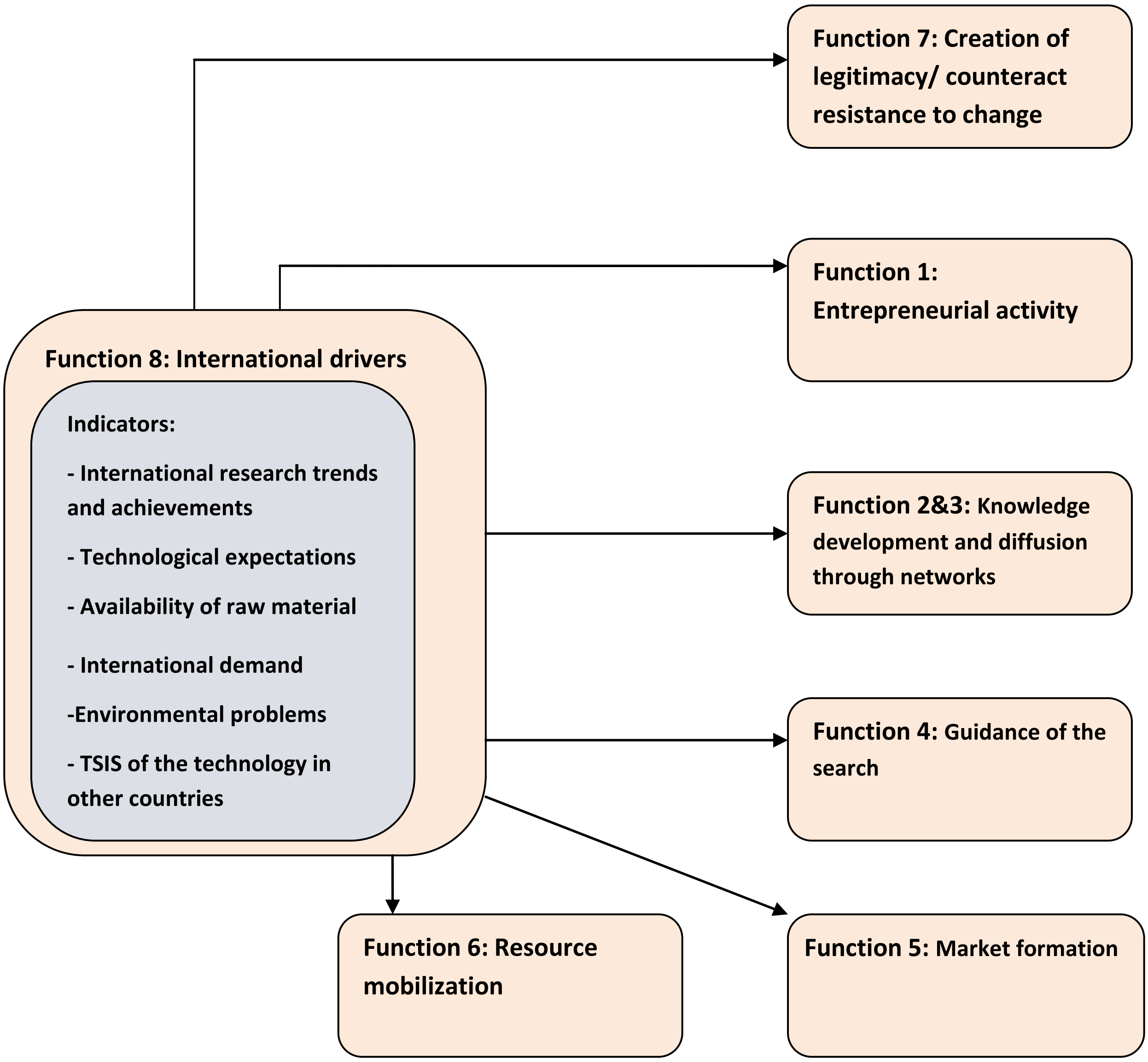


**Figure 8.1: The new Function 8 and its relation to the other functions of FIS**

As stated earlier, the indicators of Function 8 are not really influenced by the TSIS of a certain country but they do influence the TSIS in their turn, these indicators could be considered as being part of the Landscape. Therefore this function could bring the TSIS theory one step closer to a combined framework with the Multilevel Model as is proposed by Markard and Truffer, 2008.

Further research could be done to further merge the TSIS theory with the Multilevel Model. This holds for the Regime and the Micro level. The role of the incumbent technologies and their TSIS is not explicitly mentioned using FIS. This could be because their actions are linked with the role of the government. The government either wants to make an end to a certain configuration of the energy sector or it does not. If they do they introduce tax benefits, subsidies and other measurements to stimulate the new emerging technology. So the influence of the TSIS of incumbent technologies should be presented as part of Function 4 and how they influence mainly the government.

The Regime is too widely defined to really point out indicators that together would form a separate function. Entrepreneurs could also already be part of the regime, for example Shell. This company is very active with the incumbent energy source (fossil fuels). PV would actually be a threat to their business, but still they started activities around PV. Research institutes also do research on other technologies. So defining the line between regime and Micro Level with FIS is very difficult. Implementation of the Regime and Micro Level in FIS is therefore still a challenge for future researches.

### 8.1.2 Changes to the existing functions of innovation systems

It was noted during the research that some functions use the same indicators. For example, Guidance of the search indicates the opinion of the government about a technology. This is usually expressed by taxes and/or subsidies. Function 5 again uses taxes as an indicator. These two involve financial stimulants which are again used in Function 6, Resource mobilization. Cumulative causation, which means that one function leads to another, is difficult to identify then. When reading literature on functions of innovation systems, it becomes clear that functions have been changed a couple of times and so were the indicators. This could indicate that scholars have realized before that some indicators would better belong to a different function than it was assigned to before. This can lead to confusion because, as was the case for this thesis, one tries to find as much indicators as possible and uses different literature from different sources.

Cumulative causation becomes difficult when considering Function 4, Guidance of the search. This function regards different actors with very different expectations, roles and goals. The government, firms and users are some of these actors. It is better to separate these actors into different functions. This will also have a consequence on the indicators used in the functions. The following changes per function are proposed:

*Function 4: Guidance of the search*

To make the role and opinion of the government clear, it is better to make Function 4 all about the government. The government can have influence with regulations and with financial methods. Financial methods include subsidies and taxes but also the financing of local projects.

*Function 1: Entrepreneurial activity*

Entrepreneurs will not take the risk to start entrepreneurial activity if they do not believe in the technology. Their expectations should therefore be mentioned in Function 1, not Function 4.

*Function 6: Resource mobilization*

Availability of natural resources has already been transferred to the new function called "International drivers". With taxes, subsidies and other financial instruments of the government in Function 4, Function 6 should be all around private investors (investing companies, organizations…). Investments from international NGOs and the European community can be used in Function 8 (international drivers).

The number of employees regarding a certain technologies should then be transferred to Function 1. This immediately indicates how important the entrepreneurial activity per technology and per company is. Just listing the number of entrepreneurs does not give a thorough description about their importance for the TSIS.

*Function 5: Market formation*

This function is about the home market and its growth. This function should also express the demand and hence the expectations of possible consumers. Therefore, expectations of consumers should be part of this function and not of Function 4. It should be stressed that this function involves the home market. Else there would be no indication if entrepreneurial activity is stimulating the home market (diffusion) or an export market. As is proved for the case of PV technologies, the number of entrepreneurs does not say anything about the actual diffusion of the technology within the borders of the country. The connection between Function 1 and 5 is what indicates if the entrepreneurs are producing for the home market or for an export market.

If the government is the client or final user, their motives could be explained in Function 4. This would then lead to entrepreneurial activity (Function 1) which will lead to diffusion of the technology (Function 5).

*Functions 2: Knowledge development*

The expectations of researchers are already expressed through their research. They would not do research on a certain topic if they did not think it would lead them somewhere. The results of the researches will then influence the government's expectations in Function 4.

*Function 7: Creation of legitimacy/ counteract resistance to change*

As presented in the literature on motors of innovation, this function would only be influenced by Function 1, entrepreneurial activity. However it became clear that organizations and consumers also had an influence on some governmental decisions. For example the electricity law that forced energy companies to remunerate the electricity produced by their consumers with PV. Consumer organizations did have an influence on that decision. Therefore there should be a connection between Function 5, market formation and Function 7. Looking at the motors of innovation as made by Suurs for example, it is never the market or users [F5] that lead to stronger lobbying activities to pressure the government. On the other hand Function 7(Creation of legitimacy) does lead to market formation. This would mean that Market formation only considers the creation of a market from scratch. In this case, diffusion is not considered within FIS. And local diffusion would be measured by assessing entrepreneurial activity which, as has been proven by this thesis, is totally not a fulfilling indicator for diffusion. This is because entrepreneurs could be active in machine manufacturing or just producing for an export market.

The reason for these reconfigurations of functions is to make a clearer distinction between the Government, scientific development and entrepreneurs. Each of them has different influence resulting out of their different goals and power. Putting each important actor in a different function would also bring out the degree of importance of each one of them within the TSIS.

## 8.2 Managerial recommendations

Crystalline silicon solar cells and panels have kept the highest market share for years. These panels are decreasing in price because production is rising, mainly in China. C-Si cells are expected to have the highest efficiency at least until 2030 (See Function 4 paragraph, 4.5). This, in combination with the decreasing prices, will probably keep c-Si its high market share. The price decrease of Chinese technologies is said to be mainly due to subsidies and low interest loans provided by the Chinese government to their producers (The Guardian, 2011). Many European and American companies have complained about an unfair trade. Many big companies were nevertheless forced to transfer parts of their production to China or other Asian countries to keep up with these companies. Dutch companies involved in c-Si panel and cell manufacturing cannot do much more than trying to compete on efficiency and increasing the lifetime of their panels. It should also been taken into consideration that panels which are mainly used on rooftops of households only need a maximum production of 3500 KWh per year. If the lifetime of Chinese products is very close to the ones produced in the Netherlands, a 1% or less difference in efficiency will not make people choose a Dutch product. Transferring the production to Asia will then be the only option left.

There were high expectations regarding thin film silicon technologies. This seems to have changed, and Dutch companies like Nuon Helianthos are faced with a lack of interest from investors leading to the end of their activities (Function 1, paragraph 4.2). CdTe and CI(G)S are now the most popular thin film technologies. But these still do not have a better cost/performance ratio than c-Si (Function 5 paragraph 4.6) . Therefore producing these technologies would still be a gamble for Dutch companies. First, because of the performance inferiority compared to c-Si; and secondly because the used materials are limited.

The Netherlands is on the other hand very successful in the manufacturing of productions processes. Combining the knowledge of the companies, research institutes and universities that are available in the Netherlands can lead to the production of complete turnkey systems. An example of that is the initiation of the Cigself project (Function 3 paragraph 4.4). Chinese companies mainly use turnkey systems that are engineered abroad (de la Tour, 2011). Apparently, they do not have the knowhow to make these systems themselves. Their increasing production leads to an increase in their demand for production processes and the services that go with that. A proof of that is the increase in demand for machines made by Tempress systems for example (100% a year) (Scholing, 2011). Future focus for entrepreneurial activity should therefore be around manufacturing machines, the design of turnkey systems and commercializing the knowledge through projects with foreign companies and consulting services.

Organic solar cells, especially polymer cells still have a chance when being produced in the Netherlands. The technology is still very much in development so a lot of knowledge is needed. The life time of the cells is still just a couple of years. Therefore the application that they are used for should have the same lifetime approximately (Kroon, 2011). Therefore a close cooperation is needed between research institutes; electronics companies like Philips; and producers of consumer goods like handbags for example. Producers should enter the market when they think they are able to be productive on a short time scale. They should know the needs of their possible clients and not wait too long with the demonstration of their product. Helianthos perhaps made the mistake of not knowing the need of their customers. The marketed advantage of their flexible panels would have been the possibility to apply them on light weight buildings. The only demonstration project they had was on an IKEA building (Function 2, paragraph 4.3). Maybe better applications would have been consumer products like bags or tents. These applications would not have needed much energy as they would only be used to charge batteries for phones for example. The low efficiency would have played a smaller role then. Wafers made of c-Si would be far less attractive for these kinds of applications because they are inflexible.

Further research should focus on which applications would be lucrative for organic PV producers. Other research should focus on how to exploit the PV know-how the Netherlands has in contrast with the fast developments in Asia. A comparison with other technologies could be made which perhaps have seen a switch from actual production to commercialization of knowledge in the form of machine manufacturing and consultation.

## 8.3 Policy recommendation

The new SDE+ subsidy set by AgentschapNL provides subsidies only for systems between 15 and 100 KWp (Function 4, paragraph 4.5). Taking into account the average energy needs per household (3500 KWh) and the price of such a system, this subsidy will only be attractive for companies with big buildings. Starting a large scale project to exploit it commercially is not attractive with a subsidy of 9 cents per KWh. Therefore the subsidy only attracts companies that place the panels on their own building to get a green image and perhaps save tax and energy money in the future. Households, which proved to be very interested in PV are totally excluded.

Another issue with this new SDE+ subsidy, which was also an issue during the former SDE, is the actual realization of the system. When somebody is granted a subsidy, a part of the SDE budget is reserved to finance 15 years of subsidy supply for the production of green energy. The system has to be installed within 3 years. For the former SDE this was 5 years. However, nothing is said about the consequences of not installing the system after all. Application for a subsidy can be done for a certain amount of time after announcement of the new SDE. When the whole budget is reserved, application is not possible anymore. This means that if somebody applies for a subsidy and does not install the system, the reserved money is not used and nobody can apply for it again. Regarding the current SDE subsidy, 18 MW has been installed (Function 5, paragraph 4.6) whereas 49 MW has been applied for (Appendix A, Table A.5). This means that after 3 years not even half of the systems were realized.

Taking into account that probably only companies will install systems. They will look for the right moment. This means, they will wait until the panel prices reach the lowest level possible within the 3 years. This would be at the end of the 3 years regarding the decrease in price each year (Figure 1.5). Not only that, if they cannot come up with the costs, they will not install it. There is no fine or regulations that will force the company to install the system.

The regulations should be made clear and there should be measurements that commit the applicants for subsidies to actually install the PV systems as they planned to.

During the thesis it became clear that there are no clear procedures for installing a PV system (Function 7, paragraph 4.8)(Veenstra, 2011). AgentschapNL, the energy utilities and installers of PV panes should come up with clear guides for people that are interested in acquiring PV. Holland Solar could for example gather all the important actors and publish one clear guide on which everybody agrees. Holland Solar is also working on a guide on regulations and quality for PV installers (Veenstra, 2011),they should therefore consider to initiate a guide for consumers too.

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# Appendix A: Additional information

| | | Periods | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trade in PV pannels | Import | kW | . | . | . | . | 13160 | 23677 | 25052 | x | x | x |
| Trade in PV pannels | Sales to installers | kW | 3564 | 7750 | 5817 | 19845 | 3604 | 1663 | 1521 | 1399 | 4444 | 10669 |
| Trade in PV pannels | Export | kW | . | . | . | . | 9770 | 20942 | 22148 | 34005 | 64898 | 127419 |
| Employment | Total | fte | . | . | . | . | 147 | 141 | 232 | 403 | 566 | 588 |
| Turnover | Turnover | 1 000 euro | . | . | . | . | 89866 | 113018 | 160663 | 252488 | 412971 | 483840 |

**Table A.1: Growth of the PV market in the Netherlands (Statistics Netherlands, CBS)**

On the other technologies many others were doing research. These are described in table 4.1

| Technology | University, Research facility or company |
|---|---|
| Amorphous Silicon (a-Si) | Akzo-Nobel, Delft University of Technology, Eindhoven University of Technology, University of Utrecht |
| Cadmium Telluride/ Cadmium Sulfide | - |
| Gallium arsenide and other III-V materials | KUN, ECN, Fokker Space, Phillips |
| Copper Indium Diselinide and copper Indium Gallium Diselinide (CIS/ CIGS) | Free Energy Europe, ECN, TNO-TPD |
| Thin-film Crystalline Silicon | ECN, Delft University of tech., Dimes, University of Utrecht |
| Organic solar cells | DSM, ECN, LUW, University of Groningen, TNO-TPD, Delft University of tech., University of Utrecht |

**Table A.2: overview of research facilities per technology around 1997 (ECN, 1997)**

| | Solar photovoltaic, total | Solar photovoltaic, autonomous | Solar pv, grid conn., energy companies | Solar pv, grid connected, others |
|---|---|---|---|---|
| 1990 | 1 | 1 | 0 | 0 |
| 1991 | 1 | 1 | 0 | 0 |
| 1992 | 1 | 1 | 0 | 0 |
| 1993 | 2 | 2 | 0 | 0 |
| 1994 | 2 | 2 | 0 | 0 |
| 1995 | 2 | 2 | 0 | 0 |
| 1996 | 3 | 3 | 0 | 1 |
| 1997 | 4 | 3 | 0 | 1 |
| 1998 | 6 | 3 | 0 | 3 |
| 1999 | 9 | 4 | 0 | 5 |
| 2000 | 13 | 4 | 0 | 8 |
| 2001 | 21 | 4 | 2 | 14 |
| 2002 | 26 | 5 | 2 | 19 |
| 2003 | 46 | 5 | 2 | 39 |
| 2004 | 49 | 5 | 3 | 41 |
| 2005 | 51 | 5 | 3 | 43 |
| 2006 | 52 | 5 | 3 | 44 |
| 2007 | 53 | 5 | 3 | 44 |
| 2008 | 57 | 5 | 4 | 48 |
| 2009 | 68 | 5 | 4 | 58 |
| 2010 | 88 | 5 | 5 | 78 |

**Table A.3 Total installed PV capacity in Megawatt between 1990 and 2011 (CBS Statistics Netherlands, 2011)**

| | Solar PV, total | Solar PV, autonomous | PV , energy companies | pv, grid connected, others |
|---|---|---|---|---|
| 1990 | 0 | 0 | 0 | 0 |
| 1991 | 0 | 0 | 0 | 0 |
| 1992 | 0 | 0 | 0 | 0 |
| 1993 | 0 | 0 | 0 | 0 |
| 1994 | 0 | 0 | 0 | 0 |
| 1995 | 0 | 0 | 0 | 0 |
| 1996 | 1 | 0 | 0 | 0 |
| 1997 | 1 | 0 | 0 | 0 |
| 1998 | 2 | 0 | 0 | 2 |
| 1999 | 3 | 0 | 0 | 2 |
| 2000 | 4 | 0 | 0 | 3 |
| 2001 | 8 | 0 | 2 | 5 |
| 2002 | 6 | 0 | 0 | 6 |
| 2003 | 20 | 0 | 0 | 20 |
| 2004 | 4 | 0 | 1 | 2 |
| 2005 | 2 | 0 | 0 | 1 |
| 2006 | 2 | 0 | 0 | 1 |
| 2007 | 1 | 1 | 0 | 1 |
| 2008 | 4 | 0 | 0 | 4 |
| 2009 | 11 | 0 | 1 | 10 |
| 2010** | 21 | 0 | 1 | 20 |

**Table A.4: Additional PV capacity in Megawatt 1990-2010 (CBS Statistics Netherlands, 2011)**

| | Aantal aanvragen met positieve toezegging* | Toegezegd vermogen (MW) | Toegezegd budget (€ miljoen) | Productie in 2009 (MWh) | Kasuitgaven 2009 (€ miljoen) |
|---|---|---|---|---|---|
| SDE | 11.673 | 49 | 223 | 922 | 0,6 |
| MEP | 591 | 15 | 10 | 3.500 | 0,6 |
| SDE en MEP | 12.264 | 64 | 233 | 4.422 | 1,2 |

**Table A.5: granted subsidies and energy production in 2009 (Agentschap NL year review, 2009)**

| Stimuleringsregeling en categorie | Subcategorie | Aantal aanvragen met positieve toezegging | Toegezegd budget (€ mln) | Toegezegd vermogen (MW) | Gerealiseerd vermogen (MW) |
|---|---|---|---|---|---|
| **Windenergie** | | | | | |
| SDE 2008 | wind op land | 21 | 73,4 | 46 | 37 |
| SDE 2009 | wind op land | 58 | 1.352,8 | 466 | 32 |
| | wind op zee | 2 | 4.395,8 | 600 | - |
| SDE 2010 | wind op land | 66 | 883,2 | 464 | 2 |
| *SDE totaal* | | 147 | 6.705,3 | 1.577 | 71 |
| MEP | wind op land | 837 | 2.329,2 | 1.734 | 1.734 |
| | wind op zee | 2 | 851,0 | 228 | 228 |
| *MEP totaal* | | 839 | 3.180,2 | 1.962 | 1.962 |
| *Totaal Windenergie* | | 986 | 9.885,4 | 3.539 | 2.033 |
| **Zonnestroom** | | | | | |
| SDE 2008 | 0,6 - 3,5 kWp | 6.884 | 68,4 | 15 | 7 |
| SDE 2009 | 0,6 - 15 kWp | 3.135 | 75,8 | 18 | 6 |
| | 15 - 100 kWp | 139 | 54,5 | 11 | 2 |
| SDE 2010 | 1 - 15 kWp | 4.218 | 68,5 | 20 | 3 |
| | 15 - 100 kWp | 131 | 24,0 | 5 | 0 |
| *SDE totaal* | | 14.507 | 291,2 | 69 | 18 |
| *MEP* | | 564 | 9,9 | 14 | 13 |
| *Totaal Zonnestroom* | | 15.071 | 301,2 | 82 | 32 |

**Table A.6: Amount of PV systems granted subsidies in MW in 2010 (Agentschap NL year review, 2010)**

| Stimuleringsregeling en categorie | Subcategorie | Productie in 2010 (MWh)[1] | Kasuitgaven 2010 (€ mln) |
|---|---|---|---|
| **Windenergie** | | | |
| SDE 2008 | wind op land | 43.785 | 3,1 |
| SDE 2009 | wind op land | 7.488 | 0,2 |
| | wind op zee | - | - |
| SDE 2010 | wind op land | 6 | - |
| *SDE totaal* | | 51.279 | 3,3 |
| MEP | wind op land | 3.048.871 | 235,4 |
| | wind op zee | 678.631 | 68,0 |
| *MEP totaal* | | 3.727.502 | 303,4 |
| *Totaal Windenergie* | | 3.778.781 | 306,7 |
| **Zonnestroom** | | | |
| SDE 2008 | 0,6 - 3,5 kWp | 2.124 | 1,7 |
| SDE 2009 | 0,6 - 15 kWp | 1.473 | 0,8 |
| | 15 - 100 kWp | 431 | 0,2 |
| SDE 2010 | 1 - 15 kWp | 127 | 0,1 |
| | 15 - 100 kWp | - | - |
| *SDE totaal* | | 4.155 | 2,8 |
| *MEP* | | 4.570 | 0,6 |
| *Totaal Zonnestroom* | | 8.725 | 3,5 |

**Table A.7: Power production of systems that were granted MEP and SDE subsidies by 2010 (Agentschap NL year review, 2010)**

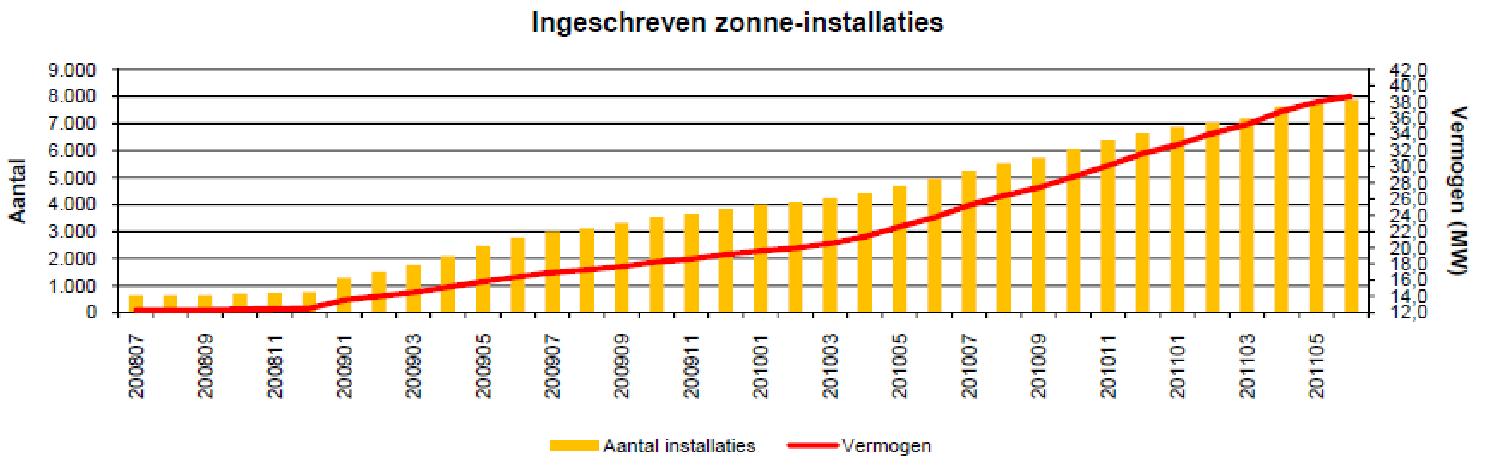


**Figure A.1: Number of PV systems subscribed at CertiQ and their capacity between 2008 and 2010 (CertiQ statistic year review 2011, 2011)**

# Appendix B: Costs and gain calculation for PV systems

**Cost calculation of a PV system**

The average lifetime of a PV system is about 25 years (NREL, 2011b). The energy yield per year in the Netherlands is about 790 KWh/KWp (ECN,2001). This means that 1 Kilo Watt Peak of solar panels delivers 790 KWh a year. Taking into account that the average household uses 3500 KWh a year, it is easily calculated that one needs about 4.5 KWp of panels.

The website Duurzameenergiethuis.nl which provides information on sustainable energy published a report on the costs of PV panels and their installation costs in the Netherlands in 2009 (Duurzame Energie Thuis, 2009). Some of the prices of the systems they have investigated are in Figure B.1. The upper table represents system prices excluding installation costs; the second table is including installation costs. The first column represents the name of the delivering company, the second is the total power of the system installed, the third column is the total price and the last column shows the price per Watt Peak for each system.

**PV-Systemen geleverd exclusief installatie (prijzen incl. BTW)**

| Leverancier | Totaal vermogen (Wp) | Totaal kosten systeem (euro) | Kosten (euro) per Wp |
|---|---|---|---|
| PFIXX | 3.360 | € 13.953 | € 4,15 |
| SolarNRG | 4.680 | € 19.890 | € 4,25 |
| BeldeZon | 1.050 | € 4.753 | € 4,52 |
| BeldeZon | 1.850 | € 8.840 | € 4,78 |
| Solarpanels.nl | 700 | € 3.490 | € 4,99 |
| Wako (Suntech) | 1.200 | € 6.000 | € 5,00 |
| Miracle-moon.nl | 350 | € 2.153 | € 6,15 |
| EasySolar | 2.200 | € 16.101 | € 7,32 |
| EasySolar | 1.100 | € 9.320 | € 8,47 |

**PV-systemen geleverd inclusief installatie (prijzen incl. BTW)**

| Leverancier | Totaal vermogen (Wp) | Totaal kosten systeem (euro) | Kosten (euro) per Wp |
|---|---|---|---|
| Energieker | 3.500 | € 18.900 | € 5,40 |
| ENECO | 2.280 | € 12.995 | € 5,70 |
| ENECO | 642 | € 3.995 | € 6,22 |
| Energieker | 1.050 | € 7.700 | € 7,33 |

**Figure B.1: System prices in the Netherlands in 2009 (Duurzame Energie Thuis, 2011)**

Considering these prices and the earlier mentioned amount of power needed for a household in the Netherlands, one can calculate that the price for an installed system that provides enough energy for a household costs at least 24,000 Euro. Taking the example of “Energieker” with 5.40 euro/Wp; and a needed power capacity of 4500 KWp. Without considering the other extra costs, taking into account a lifetime of 25 years; and an annual production of 3500 KWh, the costs per KWh would amount 0.27 euro. This is quite close to the average electricity price in the Netherlands as can be seen in Table B.1.

| | 2000 KWh single tariff | 2000 KWh double tariff | 3000 KWh single tariff | 3000 KWh double tariff |
|---|---|---|---|---|
| **Period** | **euro/1 000 kWh** | **euro/1 000 kWh** | **euro/1 000 kWh** | **euro/1 000 kWh** |
| **1996** | 105 | 100 | 103 | 94 |
| **1997** | 107 | 102 | 104 | 96 |
| **1998** | 108 | 103 | 105 | 97 |
| **1999** | 114 | 109 | 113 | 104 |
| **2000** | 130 | 124 | 128 | 120 |
| **2001** | 165 | 161 | 157 | 150 |
| **2002** | 168 | 167 | 159 | 155 |
| **2003** | 174 | 172 | 164 | 159 |
| **2004** | 182 | 181 | 170 | 167 |
| **2005** | 197 | 194 | 184 | 179 |
| **2006** | 209 | 207 | 196 | 192 |
| **2007** | 226 | 223 | 213 | 209 |
| **2008** | 229 | 219 | 215 | 205 |
| **2009** | 301 | 297 | 267 | 263 |
| **2010** | 283 | 279 | 250 | 247 |

**Table B.1: Electricity prices in the Netherlands (Statistics Netherlands CBS, 2011)**

<u>**Payback time**</u>

***Without subsidy***

The price and payback period are just an example in this case for a random company in 2009.

Without subsidy, the financial gain from the PV system would only depend on the price of grey energy. So, the owner of a PV system would have paid for 3500 KWh of grey energy a year; but that was remunerated by the PV system.

Taking the price in Table B.1 for the year 2009 (3000 KWh single tariff), the payback time for the 24,000 euro system will be: 24,000/(3500 KWh*0.267)= **25.7 years**.

***With subsidy***

This calculation is taking into account the SDE subsidy that was active in 2008 (AgentschapNL). This subsidy provided PV producers with 0.33 euro/KWh for a period of 15 years. Again considering the earlier discussed system of 24,000 euro, the payback time is calculated as followed: the subsidy provides 3500*0.33= 1155 a year. The compensation for the grey energy delivers 3500*0.267= that is 934.5 euro a year. So the system is paid back in **11.5 years** [24,000/(1155+934.5)].

# Appendix C: Interviews

| Person | Function | Date |
|---|---|---|
| Miro Zeman | Professor at the TU Delft | 17-062011 |
| Wim Soppe | Programme coordinator thin film silicon, ECN | 28-06-2011 |
| Leonie Stigter | Manager product development and application at Nuon Helianthos | 28-06-2011 |
| Floris Wouterlood | Chairman Zonnestroom Producenten Vereninging | 28-06-2011 |
| Arthur Weeber | Manager Silicon Photovoltaics group, Device architecture and integration , ECN | 30-06-2011 |
| Hans Scholing | Sales manager at Tempress Systems | 7-7-2011 |
| Michael van der Gugten | Sales manager at Smit Ovens | 12-07-2011 |
| Jan Kroon | Project manager and senior scientist at ECN, coordinator of the research programme on Organic Thin Film PV | 27-07-2011 |
| Peter van der Vleuten | Co-owner Supercis Solar; Owner Solar Technology Invest and Free Energy Consulting; former owner at Free Energy Europe | 28-07-2011 |
| Norbert Dicken | Product manager at Solland Solar | 8-8-2011 |
| Amelie Veenstra | Staff member Holland Solar | 8-8-2011 |
| Mark Pruissen | Product manager at Ubbink Solar | 18-8-2011 |

**Professor Miro Zeman , TU Delft 17-06-2011**

**Which technologies are the topics of research done at the TU Delft?**

My group is working on silicon based solar cells and especially thin film silicon (amorphous and micro crystalline silicon). There are several developments with silicon based solar cells. Crystalline silicon can be combined with thin film silicon for example. We focus on improving the efficiencies of the cells and at the same time lowering the costs. We can make complete solar cells and measure their efficiencies.

Other groups at the TU Delft are working on so called emerging technologies like Dye sensitized solar cells and solar cells that are fully based on Organic material. Then, there are also novel concepts were we look at physical aspects that can lead to an improvement of the efficiencies of future solar cells. Increasing the efficiency can for example be done by increasing the number of released electrons per photon.

We also recently worked on the degradation effects of CIGS solar cells.

**Is the research mostly focused on improvement of the material or on production technologies?**

Both, in order to improve the efficiency you also have to improve the production technologies.

**Who are the main sponsors of your research?**

We are mostly sponsored by AgentshapNL and we are also sponsored by M2i[1], an organization that finances innovation.

**What about the sponsors of research at other universities?**

They are also sponsored by the same organizations

**Which universities do you cooperate with on PV research?**

We work a lot with the University of Eindhoven and the University of Utrecht. We also work with the University of Nijmegen.

**How is the information sharing between the universities?**

There is no secrecy between the universities when we work together on projects. Of course when one us works with a company, then these companies can require to keep some information secret .

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[1] www.m2i.nl ; M2i links academic and industrial partners to encourage economic growth and a sustainable society by developing new materials through research and develop new technologies and processes. M2i helps companies increase turnover in various market sectors and emphasizes the transfer of knowledge to SMEs.

**Do you have a lot of contact with people working on other PV technologies for example through seminars?**

We gather during a conference once a year. Furthermore, when it comes to specific technologies, several specialized workshops are organized. The PV community in the Netherlands is quite small we all know each other and what everybody is working on. So when somebody needs any kind of information he/she usually knows who to contact.

**Which technologies are researched the most in the Netherlands?**

Silicon solar cells and organic solar cells. There are no researches on CdTe; and on CIGS some researches were initiated recently.

**The efficiency of each PV technology is expected to increase by approximately 5% between now and 2050. Wouldn't it be more effective to focus the research on the decrease of production costs instead of improving the efficiencies**?

If you apply PV on a large scale than 5% does matter. So when the slightest improvement is possible it should be investigated. But production technologies are also very important and there is a lot of research on that.

**Which technology do you think will reach grid parity first?**

That is difficult to say. Thin film technologies are cheaper to produce but crystalline silicon solar cells can profit from economies of scale as they dominate the market. It is also possible that some producers from China start producing thin film technologies on a very large scale and offer them for a very low price. So for now I would say silicon solar cells but anything can happen that suddenly changes the situation.

**Silicon is extracted from sand, but still there scarcity issues. Why is that?**

The scarcity problem was until 3 years ago. Back then a lot of the silicon was used by the micro electronics industry. Now there are enough producers of silicon, and as it is just sand which is abundant, there are no scarcity problems.

**How beneficial is Ribbon Growth on Substrate?**

With RGS you do not have any sawing waste anymore. You can just pour the melted silicon in the wafer form. When producing cells by sawing ingots, you could also melt the sawing waste again and produce cells with it. RGS only makes the process easier. There are no significant changes in production costs or efficiency. RGS efficiency could be a little lower than the regular multi crystalline silicon cells.

**What are the price differences between complete PV systems of each PV technology?**

Thin film technologies have higher BOS costs. Because the efficiency of the cells is lower, you need to cover a bigger area to have the same energy production as with a crystalline silicon PV panel. There the final price of a thin film PV system could be close to the price of a crystalline silicon system. However, for example with amorphous silicon on a flexible substrate you could make it cheaper. Amorphous silicon cells on glass have higher BOS costs because they are less flexible.

**Are organic solar cells already cheaper than other solar cells that are being produced?**

No, organic solar cells are not stable. That is their biggest problem at the moment. The methods to tackle that issue are at the moment very expensive and there is no cheap alternative yet. This makes them more expensive than the other technologies that are currently available. Research is now focused in finding these cheaper alternative solutions.

**Are there any other producers of a-Si in the Netherlands except for the pilot factory of Nuon Helianthos?**

No. Only Nuon Helianthos, and they still only have a pilot factory that is too small to produce large quantities and benefit from economies of scale. Now they are looking for investors to build a large factory.

**Do you know when CIS and CdTe hit the market?**

That was about 10 years ago

**What do you think about the current feed-in tariff is it enough or does the technology need more subsidies and lobbying?**

The feed-in tariff was important in the past when the costs per kwh was very different between PV and the regular electricity from the grid. That is not the case now. Subsidies follow the market developments. So now that the prices of the systems are lower, the subsidies are lower in some cases and completely disappeared for other applications. The payback times are shorter, it now only depends on the environmental awareness of consumers whether they want to pay the initial investments to buy the PV system.

Lobbying the government for subsidies is therefore also not really needed anymore.

**Arthur Weeber 30-06-2011**

**When did ECN start their researches on solar cells**

That would be in the early nineties. Around 1991, that is when the solar cell department of AMOLF came to ECN.

What kind of research is done at ECN related to crystalline silicon cells?

We do everything until the module level. We look into the quality of the silicon material and the influence it has on the efficiency of the solar cells. Research on modules is our core activity. We also do a little research on the system level where we look into what the influence of different module configurations can have on the system as a whole. So what the lifetime of the modules is, how it reacts to radiation irradiance and different weather conditions.

**Who do you cooperate with on c-Si cells in the Netherlands?**

We cooperate with cell manufacturers, in the Netherlands that is Solland Solar and we work with module manufacturers. We also work a lot with machine manufacturers like OTB, Tempress and Levitech. Tempress are at what they do the best in the world, they have the highest market share and they are a very important partner to us. We cooperate closely with Tempress and a Chinese partner called Yingli.

We work with TNO, they are however more specialized in thin film technologies, but they have expertise with industrial process which they master better than us; and when these processes are applicable to solar cells, we try to cooperate with them to apply them.

Soon we will start a STW project with the universities of Delft, Utrecht, Eindhoven and Nijmegen this project is called Flash. We have a long cooperation history with Utrecht and Eindhoven and increasingly with the TU Delft. In the field of c-Si the first cooperation was with the University of Utrecht.

**How is the cooperation? Do you have contacts with each party working on the technology or are there groups that do not share information?**

I can say that we have contacts with everybody in the Netherlands who is involved in this technology. And we share a lot of information.

**Who finances the research?**

We are mostly financed by private money from companies. An example is Yingli, but that is not only for c-Si. A lot of R&D projects are financed by solar cells manufacturers like Solland Solar.

AgenschapNL is very important for subsidies. Many subsidies are for programs on which we work with other institutions, but we can also ask for subsidies at AgentschapNL for our own projects. We also get subsidies from the European Community.

**Who provides more subsidies, AgentschapNL or the European Community?**

If we include the subsidies for programs with other institutes, then, AgentschapNL provides more subsidies in total.

**Crystalline silicon solar cells had for a long the most attention when it comes to research, do you agree with that?**

I don't know exactly. It depends on which part of the world you talk about. I know for sure that it was the case for Germany but for the Netherlands and other countries I'm not sure. For many countries, thin film technologies are the centre of attention for many years.

**Did we reach the limits when it comes to research on c-Si or is there still much to be improved?**

No we can still improve the efficiencies.

**But when you look at roadmap it says that the efficiency improvement is only 5% until 2050?**

Yes but that is on cell level. Around 2030 the efficiency of the cell should be around 25% and the module around 20%. But after 2030 there should be improvement that can increase these efficiencies even more. But improvements on the costs are more important.

**The RGS production technology is a way to lower the costs, are you still working on that technology?**

We were working on it but we are not partners regarding that technology anymore. The R&D activities of that technology went to RGS Development.

**Which c-SI cell technology is produced with RGS is that mono or multi c-SI?**

That is multi-crystalline silicon.

**Does it save a lot of costs?**

Yes you save a lot of material.

**But you can reuse the sawing waste of ingots, so you do not really waste it?**

Yes, however you still use less silicon with RGS. The main disadvantage now is that the efficiency is lower than cells made from ingots. This is because the silicon used has a lower quality.

There were two technologies that were competing with the regular c-Si from ingots, these were EFT and string ribbon material. Crystal Solar and Evergreen worked on these technologies but they quit their activities on them. The thing is, when you have new production technologies, you are not following the mainstream. This implies that machines have to be custom made for you. While, when you follow the mainstream, you can choose between several suppliers of machinery and buy them at lower prices. Production of RGS cells are not standardized by far. This makes it more expensive even though you use less silicon.

**Is there a scarcity problem with silicon?**

No. Silicon is the second abundant element on earth. There was a scarcity issue with pure silicon or solar grade silicon as the demand was much higher than the production of solar grade silicon. This is not the case anymore as solar grade silicon producers grew faster than the demand for the material. So scarcity of solar grade silicon is not an issue anymore.

**There are plans to start a production factory for solar grade silicon in the Netherlands, The Silicon Mine, does ECN have any contact with them?**

Yes we keep in touch and take an advisory role.

**Crystalline Silicon solar cells have the greatest market share at the moment. Do you think that is going to be the case for a very long time?**

I think it will be at least until 2030. The efficiency is higher than the other technologies and that will stay that way for a while. It will not have a market share that is as big as it has right now, because there are a lot of technologies that are quite successful on the market like CdTe (not for the Netherlands though) and CIS which contains Indium but researchers are working hard for substitutions for these materials.

At the moment it does not matter which technology you use, the costs per Kwh are about the same. Crystalline silicon cells have the advantage of higher efficiency, it profits from knowledge from the semiconductor industry, it is stable and it has guarantee to work for 10 to 20 years and even more.

**And what about amorphous silicon and micro crystalline silicon cells? Shouldn't they have a bigger market share since they profit from both the abundance of silicon and the use of a small amounts of material.**

The main problem lays in the efficiency which is lower for a-SI and micro crystalline silicon. They still have a long way to go but they have potential because indeed they use Silicon which is abundant and it does not use toxic material. They use a ITO layer which is a Indium Tin oxide layer but there are researches to replace this material. It turned out that improving a-Si was a little harder than what people thought 20 years ago.

In the Netherlands there is Helianthos, they are looking for investors. Internationally there are other companies but as far as I know they are not doing very well. First Solar is really the biggest company in the world producing thin film technologies and they are producing CdTe cells.

**Are there tandem cells with c-SI?**

Yes, the within the Flash program we also look into the combination of wafer technologies with thin film technologies, the so called hetero junction cells. We also worked on that with Utrecht for a while. Many companies are internationally working on these cells so there is a big interest in them. The Japanese company Sanyo is producing them and they work on them for about 20 years now.

**Wim Soppe 28-06-2011**

**What does ECN do in the field thin film silicon?**

We develop technologies to manufacture thin film silicon technologies. We focus mainly on substrate technologies. That differs from superstrate technologies which are on glass. The substrates we use are foils that can be steel foil or plastic foils.

**Do thin film silicon cells consist of amorphous silicon cells or micro crystalline silicon?**

The manufacturing technologies for amorphous and micro crystalline silicon are basically the same. Our goal is to make modules based on thin film silicon with efficiencies that are higher than the current efficiencies, so then we are talking about more than 10%. We also work on tandem cells which are a combination of both technologies.

**Are the tandem cells already on the market?**

Yes, you can buy them already. The company Kaneka is delivering modules based on tandem cells on glass for about 5 years now. There is also Iventux in Germany. You could buy their products in the Netherlands.

**Who do you cooperate with on R&D?**

In the Netherlands we work with the TU Delft, TU Eindhoven and the University of Utrecht. We also work in European projects and national project. We have a project with Tata Steel (Corus) and Delft also cooperates in this project. There is also a cooperation with the TU delft and Helianthos.

**Helianthos is taking quite a long time to start an industrial production line; do you perhaps know why that is the case?**

My personal opinion is that Helianthos took too long with their research and they started it without having a good insight their market. Once they thought they could start production, the market turned out to be different from what they thought it would be like. Now they are lagging behind the developments of the market.

**Do you think that Helianthos can change their situation soon by using their cooperation with others like ECN?**

It is possible, but then, they have to adjust their production process; and come up with cells having higher efficiencies. That can take them a couple of years.

**Do you work with a lot with producers of cell manufacturing machines like OTB-Solar and Tempress Systems?**

They are currently not involved in thin film silicon. We have worked with Roth&Rau (who took over OTB-Solar) on a roll-to-roll PECVD manufacturing process for thin film silicon PV. In 2008, Roth&Rau changed their strategy and stopped the development of thin film Si PV and decided to concentrate on heterojunction cells.

**Who finances the research at ECN?**

Research is mostly financed by AgentschapNL and the European Community. A small part of our work concerns contract research for industrial partners. Funding by AgentschapNL and the European community covers 60% of the costs and the rest is then financed by EZS funding.

**How can thin film silicon be competitive with c-Si which is currently dominating the market, are there specific niche markets?**

Their efficiency should increase in order to be competitive and cheaper than C-Si.

**Amorphous silicon performs better under a lower light intensity then c-Si does that provide any significant advantages for a-Si in the Netherlands?**

a-Si cells have two advantages: it performs better under high temperatures and it performs better at lower light intensities. During standardized tests we use a light intensity of AM 1.5, so with a clear sky. When it is cloudy a-SI performs a little better than c-Si. But the differences are not so big that it can compete significantly on these two advantages.

**What about BIPV, can thin film silicon have an advantage in that field?**

Especially the substrate technologies, since they are flexible and light weighted they are easier to integrate or to attach it to existing building elements.

**The balance of the system costs are higher for thin film technologies, is that different for substrate technologies?**

No, that is the same, that is why we need to increase the efficiencies. Because then we can lower BOS costs and hence lower the total costs of a system with thin film silicon technologies.

**Will thin film technologies soon be competitive with c-Si efficiency-wise?**

No, and it does not have to. The production costs of the cells are lower so the total sum including BOS can be lower once the efficiency is high enough. Now there is a remarkable price drop on c-Si cells from China but we are not sure to what extend that is because the costs are lower or because it due to dumping of their products to gain market share.

**What is the competitive position of the Netherlands regarding thin film Silicon?**

The Netherlands plays a significant role with their knowledge on thin film silicon. You can consider the Netherlands as being at the top regarding research and development. We have remarkable institutes and universities that accomplish great developments. So on the long term maybe we will not be leaders in producing the cells but we certainly can make a difference when it comes to science. That is also the whole point of Solliance, it is to make and keep the Netherlands one of the world leaders in the field of solar cell R&D.

**Solar grade silicon was scarce for a while is that still the case?**

The demand for solar grade rose faster than the producers could handle. In the meanwhile, the production capacity has been increased and complies with the demand. So there are no scarcity issues anymore.

For thin film silicon you need Silane gas. This can be extracted during the production of solar grade silicon or electronic grade silicon.

**Solliance has a program called Cigself where the focus is on developing CIGS cells. ECN is participating in that project even though they are not really interested in it, so why the participation?**

In CIGS they use indium which is scarce. The material has the advantage that you can make good cells with it and with relatively low costs. But is easy to calculate that indium and Gallium will get scarce and hence become more expensive when the cells are produced on a really large scale. This makes technologies like CIGS and CdTe not sustainable which is according to ECN a requirement for solar cells.

We participate in Cigself because we noticed that there was need for it from Dutch companies like Smit Ovens and Scheuten Solar. Our expertise could be helpful for the projects. These companies see opportunities in the CIGS and CIS markets and there is certainly a lot of market potential at the moment.

**Leonie Stigter, Manager product development and application at Nuon Helianthos, 28-06-2011**

**Nuon Helianthos produces a-Si solar cells is that correct?**

Well , we do not produce yet. We have a pilot line, so we are in the demonstration phase at the moment.

**What about micro crystalline silicon cells and tandem cells?**

What is being demonstrated at the moment are a-Si single junction cells. And we are developing tandem cells with amorphous and micro crystalline cells.

**Why did Nuon Helianthos choose a-Si cells instead of other thin film technologies that are available? Is that because of scarcity of other materials?**

Scarcity of other materials plays a role, but decisions for the technology have been made years ago. Back then, there was a lot of information on and experience with a-Si. We did not want CdTe as we did not want to use Cadmium in our product. We did not choose for CIS because of the availability of materials and because the information and experience with the production technologies were not advanced enough.

**Helianthos is now active since quite some time, everything started around 1999. Why is there still no industrial production initiated?**

Research and development take a long time. And it depends when an investor is ready to invest in a large scale production line.

**Are there investors at the moment and when is large scale production expected?**

We currently looking for a partner but I cannot give any further information about that. By the time we find this partner we can start production until then we cannot give any information about that.

**Have there been any demonstration projects to demonstrate the product from the pilot line?**

Yes, we applied our product from the pilot line to the IKEA building in Duiven. We are going to extend this project this year. There are also some projects planned also for applications abroad.

**Who do you work with concerning R&D?**

We have many partners within the Netherlands as well as abroad. We work a lot with the TU Delft, TU Eindhoven, the university of Utrecht and TNO. Abroad we work with Jülich and we participate in European projects.

We also work with companies that produce manufacturing machines.

**There has been some successful development at the TU Delft for example to produce a-SI cells with lower production costs? As Helianthos and TU Delft are partners, did you implement these new developments?**

We are always interested in new developments. However it is not so easy to immediately implement a new development in our existing production process.

**What are the market segments where a-SI cells can be applied and where other technologies are less suitable?**

The advantage of a-Si is that it works better with low light intensity and performs better under high temperatures. I don't know if you could say that is a niche market but it creates opportunities. We produce flexible panels that have more possibilities than a-Si on glass. Because our product is deposited on foils, they are light weighted and thus they can be installed on constructions made with light material. There are a lot of buildings that cannot handle the weight of panels made with glass.

Our product is light adhesive, so it has some kind of glue layer on the back and this way it can be glued to a surface. There is no further protection needed for the panels.

**Are there BIPV applications for a-Si?**

Our product has a protection layer to protect the cells. Other building application would also have a protection layer, so you could as well use the flexible a-Si panels for that. For now the price of flexible panels is such that it cannot compete on price with other building components. So replacing a component by flexible panels is not cheaper.

**Are there any other a-Si panel producers in the Netherlands that you know off?**

There are no producers. But you can buy them but there is not much interest for the panels at the moment because people think they are less efficient then c-SI. With efficiency I mean cost-performance ratio.

**The production might be cheaper but the final costs are the same as c-Si is that true?**

Yes because you need a bigger area due to the lower efficiency you have higher BOS costs because you need more constructions to fix the panels to the roof. This is the case for a-Si on glass, but for flexible foils you do not need any constructions.

**So your product is cheaper to apply than c-Si?**

Well we are not producing anything so what can we compare?

**Are there other producers of flexible a-Si cells in the world whose product you can compare to c-Si panels?**

There are not that many. There are a few producers, maybe 2 o 3 in America, one in Japan and one in Europe. But there are a lot for a-Si on glass. Most of the producers started their production not so long ago.

As I said, flexible a-Si will probably be used for special application like buildings that cannot take the weight of c-Si panels. Sometimes, people prefer them over c-Si panels because they do not like the look of c-Si panel. That’s why there are just a few producers.

**Nuon Helianthos is part of the Joint Solar Panel, what is you benefit as they mostly do fundamental research that is usually focused on organic PV?**

That is Nuon, but we represent them in this case. But research is not just on organic PV but also other materials that are used in our cells.

**Do you work with companies that are specialized in BIPV like Oskomera?**

We do not really have common projects but we know each other and we keep contact. They are specialized in the construction of facades. These are per definition not flexible, so perhaps in the projects they have done they did not use flexible PV panels.

**Does Nuon promote the use of solar panels?**

They are involved in PV. But it is not their biggest interest; they made the choice to invest more in wind and biomass energy. During the SDE subsidy they also delivered solar panels to their customers but I do not if that is still the case.

**Floris Wouterlood, Chairman of Zonnestroom Producenten Verening, 28-06-2011**

**When was the organization initiated?**

The ZPV was initiated on September 1st 2003. Actually, because of anger. Anger, because the government was messing around with the subsidies, again. And to gather people around who can, because of their quantity, have influence on the institutions. Back then, that was the Ministry of Economic affairs and the ministry of Housing, Spatial planning and the Environment. Now we only have to deal with the Ministry of Economic Affairs so that's easier.

Within the scope of Solaris, Eneco and Nuon delivered some PV systems under an offer they called Sun Power. Greenpeace also provided system under the scope of Solaris. The inverters were defect and the companies acted like there was nothing wrong. They told their customers to go to NKF, a Dutch company that delivered the inverters. So, we gathered to make a change. Eneco, Nuon and Greenpeace sold us the systems so if any component is not functioning well, they have to fix it. Eneco and Nuon finally came through because we threatened to talk to the media.

**Can you give examples of direct results that were achieved thanks to your activities?**

Well first that you can deliver energy back to the grid. That was not possible.

**But according to the Electricity Law which was written in 1998, delivering electricity back to the grid was possible up to 3000 Kwh.**

No, the law was admitted and did not come into force yet. After 2003, the utilities had to accept that their customers could deliver electricity back to the grid. They did not want to let that happen before, just like a water company that does not want you to deliver water back into their water supply system. The utilities saw problems in the disturbance that delivering back to grid could affect. They had to take measures adapt to these disturbances.

Besides, utilities had to give their customers a reasonable remuneration for the electricity that they deliver back to the grid. This "reasonable price" was not set by the government. And if the utilities thought that paying nothing was "reasonable", they would not pay you back.

Setting a limit to the remuneration on the energy to be delivered back into the grid is ridiculous. So we also lobbied against that. Thanks to our efforts, among others, they changed that last year to 5000 KWh and some utilities even set no limit at all to the amount of energy that can be delivered back.

Another issue is that utilities would agree for their customers to deliver energy back, under the condition that they change their meters at home. The old meters with a turning mechanism turn one way when you use electricity and the other way when you deliver, this way they just count back and they cannot check how much you delivered. They always want to know this actually because that provides them with Green Certificates. But, the utilities tell the customers to buy the new meters themselves.

We are also proponents of the “zelfregelingsmodel”.At the moment when you deliver electricity at a remote location and you want to “transport” that to your house, you have to pay taxes. We wanted these taxes to be cancelled but the government did not agree to that.

**Who were the other organizations that led to the changes you just mentioned?**

These were mainly people in the parliament who were in favor of green energy.

**What did you think of the SDE subsidy?**

That it was too complex. You could get a subsidy when you have PV system, under the condition that it not more than 300 KWp. For each KWh that you produce you get a SDE subsidy. Therefore you needed a second meter between your PV System and your regular electricity meter. This meter only measures the amount PV power you produced. Off course you do not deliver everything to the grid but you also use some of it yourself. Then your regular meter measures what you delivered back and that is remunerated. The remuneration is on the production costs, not on the taxes. That has to be handled by the tax inspector, they do not give that back.

Now you have the SDE+ which is only applicable for large systems. This way, small systems of households are not included and thus the government has fewer problems to deal with, on our expense.

**What are other measures to stimulate the market?**

A feed-in tariff according to the German model.

**Is that enough?**

Yes, look at Germany. They have 150 GW of solar systems installed.

**The prices of PV-systems are actually decreasing so fast that you actually do not relay need a feed-in tariff anymore? What do you think of this statement?**

Okay, but that is no stimulation of the market. Without the feed-in tariff of Germany their solar industry would never have grown that fast. And yes if a conscious person would calculate what they pay on energy taxes etc for electricity from utilities, they can easily come to the conclusion that with PV they are much cheaper off, and their system is paid back within 15 years. It depends on the investment instinct of people, They will easily spend a couple of thousand on a car, but when they have to do this on a PV system and they hear about a payback time of 15 years they hesitate.

**How do you make sure that the government listens to you?**

We cannot reach the government directly, that’s what the electorates do. We have some contacts at AgentschapNL and some members of political parties. But, these parties are now part of the opposition. That does not lead to changes in policies. We now try to make people conscious of the investment possibilities with PV.

**How do you reach these people?**

The media, internet. We have stands on fairs and markets. We do interviews and we write articles.

**You now have members with 2.9 MWp worth of PV systems. What about the others who have PV systems why didn't they join you?**

We have 1300 members. The others are just not interested. People do not know very much about energy in this country. People get interested once they have problems with their systems or their utilities. So in times of need.

**Do you have members that do not have PV systems?**

Yes, people who are interested in installing a PV system and who want advice. They profit from our technological know-how.

**Do you lobby for any specific PV-technology?**

No, we care for sustainable energy in general. So, PV, but also wind and solar thermal. But not specifically for a PV-technology.

**Are there any other organizations that you collaborate with, like Holland Solar?**

We work with ODE (organisatie voor duurzame energie). We do not work with Holland Solar because they are a branche organization. We are a consumers' organization. But we have demonstrated together a couple of times.

**Do you have any sponsors?**

No, because we are a consumers organization. If we would be sponsored by companies, then there is a conflict of interest. Only our clients pay an annual amount of 10 euro. That's also why we do not go to conferences because the entry prices there are so high that we cannot afford that.

**Hans Scholing, sales manager at Tempress Systems, 7-7-2011**

**What are the activities of Tempress Systems in the field of PV?**

We are suppliers of equipment that is applied to cell production line. What our equipment actually does is applying the Phosphor diffusion and Boron diffusion into silicon wafers.

**So you are only active in the field of c-Si?**

Yes only c-SI, mono and multi c-Si.

**Since when is Tempress Systems active in the field of PV?**

We have been active for a longer time in the field of semiconductors. In the field of PV, we are active for about 20 years now. It started with projects for oil companies like Shell and BP who wanted to acquire a green image.

**You also manufacture Chemical Vapor Deposition (CVD) machines?**

In the semiconductor field you have deposit several layers of oxides on top of each other. To create differences between the layers, you have to come with a solution with which you can apply the layer under a lower temperature. Low pressure CVD entails that you go from an atmospheric process to a vacuum process under which you can use lower temperatures to apply a second deposition.

**This means you also apply the other layers needed to form a solar cell, like protective layers?**

Yes we do a lot of research on that. We have systems at our R&D department that apply the antireflective coating layers. This happens through Plasma Enhanced CVD and Chemical CVD. For this technology we are now looking to find competitive solution in that field.

**You have 40% of the market how many machines a year are we talking about then?**

The demand for our systems have been rising very fast. The last years the demand rose by 100% per year. That is about 12 to 14 GigaWatt.

**Who are your main competitors?**

The competition consists mainly of Centrotherm in Germany. Their market share is perhaps 5% below ours. There are at the moment also some companies in China.

**Where do you sell your products?**

Mainly to China and Taiwan. Most sales take place in China, then Taiwan and then Korea. With China we have already been working since the eighties on optical solutions.

**What about Germany?**

We only work together on R&D but we do not really sell them products. Untill 2006, Germany isolated itself on this field.

**Do you have any clients in the Netherlands?**

No, only when it comes to R&D we have some systems at Solland Solar and ECN.

**What are your R&D activities?**

Our Systems can be found in many institutes and companies in Europe. They are used also for joint European projects. We have systems in Germany at the ISFH institute in Hameln and at ISE institute in Freiburg. We have R&D systems at Q-cells in Germany and Imec in Belgium. In the Netherlands we work with ECN and TU Delft but in Delft we cooperate more in semiconductor technologies. Developments in the semiconductor industry also have influence the solar cells technologies, then we talk about nanotechnology and HIT cells. There are also interesting developments with Ion implantation. Tempress also bought a company in China that is involved in Ion implants. So we look into the possibilities with this technologies and how we can adapt our systems. These Ion implants can be applied maybe around 2012.

**Do you only make money by delivering the systems that you sell or also by adjusting the systems for your clients on the long term?**

We do not only deliver a product, we deliver the process. Looking at the clients we have now, we always keep in touch. Sometimes clients ask us if we could apply some new concepts or innovations. We also earn money by doing that. We have a long term relation with our clients.

**Do you have any activities in the field of thin-film PV?**

No, the reason for that is that 95% of the mainstream market is based on c-Si. Thin-film is a niche market and we have seen many examples of failures around the world. And the production technologies are not really in synergy with what we produce.

**So you don't think that thin-film technologies are taking over any time soon?**

No. c-Si has seen a tremendous price drop the last couple of years so it is becoming a serious option to compete with grey energy.

**Is the price drop because of economies of scale or because of efficiency improvements?**

Economies of scale is a main reason. The production processes are very standardized and relatively easy. But efficiencies also play a role certainly for c-Si, companies reached 15.4% efficiency and will soon reach 16.5%. And the price of silicon is decreasing.

Oil prices are rising due to the rise in demand and decrease of reserves. This gives the opportunity for c-Si cells to become a serious alternative.

**Do you receive subsidies?**

We do receive subsidies for projects that we participate in. There are also developing projects for which we can receive subsidies.

**Would you say that machine manufacturers are keeping the Dutch solar cell industry alive?**

No, that's not how you should see it. If you would ask what is the Netherlands good at, I would say there have been a lot of spin offs which have a lot of knowledge and they can produce high quality equipment based in this knowledge. So turning knowledge into applicable technologies is the main skill of the Netherlands.

**Do you participate in any lobby activities for the solar cells market in the Netherlands?**

Not really, but we do worry a little bit about the initiatives of the Dutch people and the Netherlands when it comes to PV. The prices of PV systems are now such that you have reasonable payback times but still there not enough initiatives in the Netherlands to stimulate the PV system market. Energy companies in the Netherlands see PV energy producers more as competitors, so they rather not help you.

The oil industry is for the government at the moment too lucrative and import to give it up and focus on PV. They make a lot of money on energy taxes, they lose this when we all start to use PV.

In Germany they look more on the long term and think of new solution to make money with green energy like PV. A big problem with renewable energy like PV is the storage. With the upcoming electric cars, you can store the excess energy in car batteries etc. Germany is already thinking of new solutions and business models like this. They also have a big automotive industry which stimulates this kind of thinking even more. They just like to be a step ahead when it comes to new technology applications.

Tempress started with an initiative called PV Privé. With this initiative we try to look into the possibilities for us as a company to apply PV energy. For example, we could collectively buy a big PV system and share the benefits of it. This way you do not have a large initial investment per person but still can make a little benefit. If this works on a small scale within our company we can perhaps commercialize it.

**Michael van der Gugten. Sales manager at Smit Ovens. 12-07-2011**

**What are the activities of Smit Ovens in the field of photovoltaics?**

We focus on everything that has to do with technical processes for the production of thin film solar cells. We work on receivers of about 6 meters for sun collectors like those of Schott solar. We do not make machines for the whole process for the manufacturing of thin film solar cells but just parts of it. We do not work on sputter technology. The thin film technologies we work on are amorphous silicon, micro-crystalline silicon, CdTe and CIGS. There are several competing technologies with which these solar cells are manufactured. For CdTe for example there is a production technology called closed space sublimation where Cadmium telluride and cadmium sulfide are damped in vacuum; and there are atmospheric technologies in which these processes take place. For CIGS there are also many processes, you can use copper damping or electrochemical deposition of copper, indium and gallium, you can use sputtering. What we do is selenium deposition under an atmospheric pressure; and re-crystallization of CIGS. You have to make a crystal structure in the material which is the active part of the material. We also work on the deposition of cadmium sulfide which is a buffer layer for CIGS and also used in CdTe cells, we can do that in a thermal process.

For each thin film technology we deliver machines for a part of the production process. For amorphous silicon there are not so many activities anymore. The company applied materials with their Sunfab factories were big customers but they quit their activities. Even CIS and CdTe producers have taken steps back because producing the technologies it was not viable anymore. The company Applied materials stepped out of the thin film solar cell business because they were not making profits with it and they have plenty of other products that they can put their focus on, they are active in the semi-conductor industry. There is another company for which we only deliver a small part of the process consisting of the preheating and cooling.

**Since when is Smit ovens involved in PV?**

Since 2004. If you look at the history of Smit Ovens, we have been involved in the old television screen industry, glass and printed electronics. Smit Ovens turned to PV when the business for the old fashioned TV screens collapsed due to flat screens' introduction around 2001. So actually in 2001 already started to look into possibilities for PV.

**On the website of Smit Ovens there is an interview with the CEO in which he says that there is almost no competition in your technology field. Why is that?**

Of course there is some competition. You have to look at it in a different way. There only a few customers worldwide. Let's say 20 companies for CIS, 10 for CdTe. There are 3 or 4 players for that market. Smit ovens started quite early in finding ways to tackle problems in the production process and therefore we acquired an advantageous position in the market. We are now working on a second generation CIS production machines, the success of these machines will determine if we stay leaders in that market so we do face some high risks. Competition has to be taken seriously and it pushes you as a company to innovate. Without competition you do not feel the pressure to innovate and another company can come out of the blue with a better product and pushes you out of the market.

**What is the market share of Smit Ovens?**

In the market for the technologies we deliver we have about 50%. That is not to confuse with the market share of thin film solar cell manufacturing machines, remember we only deliver parts of the process. So comparing to the turnover in the whole industry we have about 3 to 4% of the market.

**Which technologies sell most at the moment?**

CdTe is has the greater market share and hence the demand for its production technologies follow this trend. We see that CIGS is an important runner up, it has great potentials. CIGS has a potential of 16% in efficiency. However, it faces many problems in creating stable mass production processes. There companies like Avancis, Hyundai, Solibro of Q-cells, Solar frontier from Japan is a big player. But their production capacity is not comparable to CdTe production capacities.

**Which of these companies are your clients?**

That is secret information that I cannot share.

**Which countries do you export your products to?**

Especially to America and Asia and we have some clients in Europe, but none in the Netherlands. Most demand is for CdTe. CdTe as such is not poisonous, however in some combinations it could be. The production countries are aware of that but the business does employ many people and keeps the economy going so there is some kind of “Sword of Damocles” hanging over this technologies and we can’t really predict the future. CIS suffers less from this problem, it also can contain cadmium but there are alternatives to that, so there are still opportunities.

**What are your activities concerning R&D?**

A certain percentage of our turnover is spent on R&D, about 7 to 12%. We do research in line with our production machines. So, for example we look into the improvement of crystallization machines.

**Are some technologies in favor when it comes to R&D?**

We focus on cost of ownership for the customer. Therefore we tend to non-vacuum processes, but there is no favor for a certain cell technology.

**Do you cooperate with Dutch universities, companies or institutes?**

We work with the University of Eindhoven, TNO. We also cooperate within the Solliance cluster.

**Regarding Solliance, part of it is the Cigself project in which Smit Ovens participates. What are the goals and has been reached so far?**

The goal is to establish a CIS research laboratory here in the region. Solliance is the name of a number of institutes Holst centre, ECN, TNO and Imec. So an institute is being created to focus on CIS and realizing a pilot project. This way you can directly apply new processes steps created by companies and institutes and assess its usefulness to the whole process. In the Netherlands we have knowledge about several process steps at different organizations but none of the organizations has full knowledge about the whole process. Cigself aims to combine the knowledge acquired in all involved organizations of the Netherlands. As far as what has been reached with Cigself, as far as I know, about 99% of all process technologies have been chosen and we are now building them. The parts we have to deliver are almost ready.

**Is the goal then to create a spinoff?**

No, I think just an open innovation platform. So when you have a new technology you can test its usefulness in the pilot line.

**Who do you exactly work with regarding each specific PV technology?**

For CdTe we do not have collaborations within the Netherlands. For CIS we mostly collaborate with TNO. Because we do not deliver key components for a-SI and micro crystalline silicon cells we do not have collaborations on that field.

**Smit Ovens is part of the Solar Industry Platform which functions as a link between the government and the solar cell industry. Can you tell something about that?**

It is the first time I hear of this. Probably this is something the CEO is involved in.

**Would you say that the machine manufacturing companies keep the solar cell industry going in the Netherlands, because we do not really have many cell manufacturers except for Solland Solar?**

We only have Solland Solar indeed, and I recently read that they had a management buyout, which means that Delta, the company that owned Solland Solar sold the company to the managers. But to come back to the question, we deliver important parts for the industry but I cannot say that machine manufacturers are who are keeping the business going.

The challenge for the Netherlands is to turn our tremendous amount of knowledge to products that can actually be sold. I think the problem lies in the fact that Small and Medium Enterprises have difficulties to attain subsidies to start projects. The subsidies usually go to institutes. There are of course exceptions like with Solliance and Cigself.

**Who provides Smit Ovens with subsidies for projects?**

We receive European subsidies like Eureka**.** A lot of money is spent by the government on institutes. As a company you cannot access subsidies because these go to the institutes, we have to put our own money into projects. When we have projects with institutes we do get subsidies but specifically for the projects.

**Do the subsidy providers express any preference for a certain PV technology?**

No it depends on your plan and its viability.

**Jan Kroon, project manager and senior scientist at ECN, coordinator of the research programme on Organic Thin Film PV. 27-07-2011**

**What kind of research is done at ECN regarding organic PV?**

Around the mid-nineties we started doing research on the Dye sensitized cell or Grätzel cell. I personally started at ECN in 1996 and I was working on Dye sensitized cells. But I also had the task to look into the possibilities with polymer solar cells. That was kind of an academic topic at the time. My task was to look into practical applications of polymer cells and cooperate with several universities regarding that topic. So there were two parallel paths one for Dye sensitized and one for polymer solar cells. Projects with polymer cells started at ECN around 1998 and subsidies came from Novem. On that project we worked together with the Technical University of Eindhoven and The University of Groningen and Philips Research. The goal was to develop better materials to improve the efficiency of the cells. Efficiencies were very low at the beginning, around 1%. We looked for better materials and processes to improve the performance of the already existing materials. We also wanted to understand the mechanisms behind the technology as knowledge on the topic was still basic. Efficiencies were not high but the collaboration resulted in nice results. It also triggered many projects in the Netherlands and abroad. The research was also encouraged through developments in organic electronics like OLEDS (Organic Light Emitting Diodes) Philips was very active in that field. The technologies and processes behind both fields were very similar.

Then a program under the Dutch Polymer institute was initiated. This is a public and private collaboration between companies and universities partly financed by the government. Therefore, the projects we started using EET subsidies could be done on a bigger scale with DPI. We still work with DPI. Companies could invest in research for a certain amount of money and the research budget was increased fourfold by additional support from research institutes (25%) the government (the Ministry of Economic Affairs) (50%). This started around the year 2002-2003 and the polymer OPV programme is still ongoing.

Already before 2010 you could notice activities from companies and research institutes to look into scaling up the processes for production. So, how to cover larger areas with small cells. Konarka, an American company based on venture capital is the frontrunner regarding this technology and they looked into the possibilities for large scale commercial production of organic PV. They wanted to look into the possibilities to cover large areas with photoactive semiconducting materials based on conjugated polymers and fullerenes. So they developed print and coat processes. These processes were already used in other industries and have to be made suitable for organic PV. The first prototypes have been made with these processes. To come back to what we do at ECN, we also look into these processes and we represent the bridge between the academic world and the industrial world. TNO has the same role. They started the Holst centre in 2006 to develop organic electronics (not Dye sensitized). Dye sensitized has been developed at ECN but we gradually quit our activities regarding this technology. We worked on it for a couple of years and participated in many projects. The goal was to start a spin-off company based on our developments. We looked into the possibilities to attract investors but that did not work out since investors prefer short term profits and we still needed time since the technology was and still is not mature enough. Therefore we focus now on polymer cells.

**Is that a trend at the moment that Dye sensitized cell research is being dropped?**

Well, when you look at polymer cell technology, they profit and follow up on developments in the organic electronics field. When you look at Dye sensitized cells, it is more of a stand-alone activity. It is a photo electrochemical system with fluids and organic material. The developments are ongoing for a while and people are wondering if something is ever going to happen. Therefore, the strategy with these kinds of technologies is not to wait too long until it is good enough to place on rooftops. To apply the technology on rooftops, it has to be stable and the lifetime should be long enough.

**What is the lifetime at the moment and what are the applications?**

The ones developed by Konarka have lifetimes of a couple of years. And the first applications are used for only last a couple of years so then it is okay. Konarka delivers to a selective group of customers. Cells are used now for mobile phone chargers and they are integrated into handbags for example. Konarka also creates large surface cells for parasols.

**Is there a production facility in the Netherlands?**

No, and our goal with the alliance with Holst Centre is to develop the print processes further and find cheap encapsulation technologies to provide end users with these machinery. We are talking a lot about Konarka but of course we want many more companies to start similar activities, also within the Netherlands. Then, the technology can become mature. But it will take some time before OPV will be suitable for power supply on rooftops. Then, we need cells of at leat 10% efficiency which are stable and that takes at least ten more years. Thus, we need to start production for small (consumer) applications because else we will be spending money on something that is possible in 10 years that won't work because investors will not take that risk. So we need the niche market to prove the technology and get the experience with it.

**Is consumer electronics the only niche market?**

There are more. Konarka also produces semi-transparent panels on flexible substrates, for which you can use different colors. That is an advantage of organic PV, the color variety. So BIPV applications should be possible with organic PV, here esthetic aspects are important for example in windows or facades. That does not need to take 10 years because the efficiency does not have to be very high the energy production is then a convenient addition. However, lifetime of the material is of importance. But for power supply via panels on rooftops, OPV is still too immature and expensive.

**How expensive it OPV at the moment?**

That difficult to calculate especially because the material is too immature and there are no big scale production facilities. So, I would say it costs 10 euro/Wp instead of the targeted 0.5 euro/Wp. The small laboratory cells have efficiencies of about 4%, so for larger areas you have a lower efficiency of at most 2%. That all contributes to the price.

**Why is a cell with a larger area less efficient?**

To cover large areas you make modules. These consist of several small cells because one cell produces between 0.6 and 0.9 Volt, depending on the materials used. So to create a high voltage you need to connect several cells in series, and you then you have ohmic losses. If you make cells with large areas the material has a larger internal resistivity and then you lose power. That is also why we use several small cells. That holds for each PV technology.

**Can you sum up some advantage and disadvantages of OPV that you did not mention yet?**

With printing and coating you can integrate the cells easily. Flexibility and semi-transparency has also advantages. The advantage on the long term is the low price. Another advantage of the printing is that you can produce a lot in an easy and fast way. You can manipulate the absorption spectrum by changing the color of the cells. Disadvantages are the ones I also mentioned earlier.

**You mentioned cooperation with universities, who do you work with?**

We collaborate in the Netherlands especially with the university of Eindhoven and Groningen through projects. They have been involved in OPV since the beginning. Kees Hummelen is one of the founders of fullerene that is used in organic PV. He worked in America and he worked on modifying C60 spheres to make them soluble in organic solvents. He now has a group in Groningen but also a company called Solenne selling fullerene for the research market and for companies.

In Eindhoven there is Rene Jansen. We also worked a lot with the TU Delft but not that often anymore but we do collaborate indirectly through the Dutch Polymer institute. These are the groups of Laurens Siebbeles and Tom Savenije.

We also have international collaborations with for example with Imec from Belgium. They perform the same kind of research program and we want to involve them to create some kind of Benelux front. And other institutes all over Europe.

**In 1998, there were two clusters and ECN was involved in both, one with TU Eindhoven and Groningen and the other with the TU Delft and Wageningen University? What were the activities of both clusters?**

Indeed. The collaboration with Delft, Utrecht and Wageningen was around the first project of organic solar cells in the Netherlands back in 1992. I was involved because I was doing my post-doc in Wageningen. The project involved an idea from Wageningen regarding an antenna solar cell based on organic molecules deducted from photosynthesis. The idea was to recreate photosynthesis in an artificial way. That is not the same as Dye sensitized. We did not want to make use of conducting fluid which is the case for Dye sensitized cells. It turned out that that was not that straight forward, that's why we continued Dye sensitized cells. The collaboration of Eindhoven, Groningen and ECN started around the end of the other collaboration and it was concerning with polymer cells.

The financing for the project of artificial photosynthesis was gradually ended.

**How open is the information sharing and collaboration in the Netherlands regarding organic PV?**

Most research is academic so very open. As the technology is so immature it is not wise to keep information to yourself because you can learn from others and they learn from you. With Holst Centre for example we work based on an open innovation model because one cannot solve everything on his own.

**Are there companies that showed interest in the production process developed with Holst Centre?**

That is the issue with OPV here, because they can give guidance for research topics. There are some machine manufacturers that show interest but not really end users. Therefore we have to show the possibilities and push the technology even more. There is a company that showed interest in OPV for light sensors. So that is not for energy production but another technology based on the same process.

**Are there any other collaborations in which ECN is not involved?**

Yes. We cannot get subsidies from FOM or NWO programs because we do not perform fundamental research. Recently a research project in Groningen acquired a fund from FOM. We do not see that as competition because FOM programs are published and we can also profit from their knowledge.

**Do you think that OPV will finally take over the market?**

The vision was always that we have crystalline silicon and that gradually that will be taken over by a second generation of thin film cells and then, the third generation consisting of OPV will take over. That vision turned out to be incorrect. C-Si cells will be there for a long time and they are also still developing and becoming cheaper. Thin film cells will take a part of the market as their efficiencies improve too, but we will finally have some kind of co-existence of all technologies.

**Do you agree that thin film and OPV cells will not be competitive with c-SI regarding efficiency, but their competitive advantage will be flexibility and esthetic aspects?**

Absolutely. The second and third generations have to compete on markets for which c-Si is not suitable. And these two generations have to show their advantage compared to each other. CIGS for example can also be printed on flexible substrates and it has high efficiencies, and then when it comes to flexibility you won't choose OPV. So competition has to be on specs.

Thin film market share will increase but c-Si will stay important.

**How will the developments be in the Netherlands considering the market?**

Because we did not have a steady subsidy system and that decisions are quickly changed we did not develop a strong home market. That's why we do not have many panel and cell producers because investments become risky. Now taking into account the cheap panel from china, we will not develop a strong panel and cell industry. Solland Solar also was looking for investors and management finally bought the company over from Delta. In Norway there was a producer of cells that decided to close down their production facilities in Europe. So producing in Europe is not so attractive anymore. Therefore, we have to compete on making manufacturing machines and that's what we are doing. The Netherlands has a good reputation regarding their know-how. The challenge will be to be one step ahead of Chinese regarding manufacturing machines so once they copy a machine or reverse engineer it we already come up with a new and improved production process.

Solliance for example is one of the competence centers that aims at improving our knowledge regarding thin film PV and stimulate the local activities on PV.

**Interview with Peter van der Vleuten; Co-owner Supercis Solar; Owner Solar Technology Invest and Free Energy Consulting; former owner at Free Energy Europe. 28-07-2011**

**At your company Free Energy Europe, Amorphous silicon solar panels were sold. Where were these panels manufactured and where were they sold?**

The amorphous silicon panels were made at my factory in France. We did not sell them in the Netherlands but in developing countries, mostly in Africa. I started Free Energy Europe in 1998 and sold it to another Dutch company (WWE Sustainable Solutions, who founded a daughter company in France, Free Energy SAS, for this purpose) in 2006. Free Energy SAS company went bankrupt last year.

**What is the market share for amorphous silicon solar cells in the Netherlands and do you know any demonstration projects?**

The market share for amorphous silicon cells is negligible in the Netherlands and I do not know any demonstration projects.

**Do you think that amorphous silicon panels can still be competitive with c-Si? Or only in flexible form like the ones developed at Nuon Helianthos?**

I think amorphous silicon panels have no future in them in any form. The main reasons are relatively low conversion efficiency, low production speed and high investment costs for production equipment (mainly vacuum equipment).

**Now you are working on CIGS with you company Supercis Solar. Does that mean you are also involved in CIS?**

I think CIS is a collective term and CIGS is a particularization.

**Since when are you involved with CIGS and Supercis Solar?**

I have been involved with CIGS since 1997 and we started Supercis Solar since a couple of months.

**Are there any parties that you work with considering research on CIGS in the Netherlands?**

There are collaborations on the agenda with TNO and ECN.

**When do you think your product or CIGS will be mature enough to compete with c-Si?**

Within a couple of years.

**Regarding CIGS there is a collaboration under solliance called Cigself. Do you think there are so many parties involved in this collaboration to spread costs and spread their risks?**

No, I think they all have great interests in this collaboration.

**Which technologie have had most investments in the Netherlands?**

Crystalline and amorphous silicon cells

**Are you involved in the Solar Industry Platform?**

No, I do not know this platform

**What are the difficulties that entrepreneurs in the PV field, like you, have to cope with?**

We have a lack of finance for our projects and developments. Due to a lack of encouragements from the government we do not have a strong home market. You see that in Germany they do encourage PV through feed-in tariffs and the result is a strong home market.

**Norbert Dicken, Product manager at Solland Solar. 8-8-2011**

**At the moment Solland Solar is making and selling crystalline silicon solar cells. Do you also look into the possibilities with thin film cells with R&D for example?**

No, we only make and sell crystalline silicon cells and in October we will start selling crystalline silicon panels.

**Don't you think the market will be taken over by thin film cells?**

At the moment crystalline silicon solar cells have the highest market share. Thin film cells are indeed cheaper than crystalline silicon wafers but you need more space to install them and that bring extra costs like for land ownership or rent. Regarding the limited amount of space on rooftops c-Si is usually chosen.

**How much of your production is sold in the Netherlands?**

We do not sell anything in the Netherlands. The Netherlands is sadly not significant when it comes to PV market. We have customers in Germany for example Solon, that is our biggest customer. Then we have Centrosolar and Heckert Solar. Then we have two customers in France and three in Italy.

**How about Asian countries that active in PV like China?**

We don't sell our products there but we do buy wafers from Chinese producers. The prices are so low in China that we cannot make any difference in that market.

**Can you notice the effect of the cheaper Chinese products in Europe?**

When it comes to the cell business we certainly do. We are one of the few cell producers left in Europe.

**So what do you do to deal with their competition?**

We cannot do a lot. The Chinese companies receive a lot of subsidies to buy production machines, and in Europe we cannot get subsidies for production. Our reaction to their competition is to switch to the production of modules instead of cells so we will now focus on the end user.

**And where will you buy the cells when you switch to modules?**

That is not sure yet. Perhaps we will use our own cells or we will buy them from for example China.

**Why the switch to modules? Aren't there module manufacturers in China that will compete with you?**

Because the margins we can get on that market are bigger. So by selling to module installers and end-users. But actually also for modules there is a drop in demand. In Germany, it was expected that in total 3.5 Giga watt would be sold by the end of June. However, it turned out that only one fifth of that amount was sold. This gives an impression about the market, it goes up and down and not even in a predictable way.

**There has been a management buy-out at Solland Solar. So the managers bought Solland Solar from the company Delta. Why did Delta want to sell the company?**

Delta bought Solland approximately 4 years ago that was when production was shifting towards China. Now only a few producers are left in Europe.

Now, the management took it over and we try to make the best out of it. Now that the company is in hands of the management of Solland Solar it is easier for us to negotiate with customers without pressure from investors.

**Solland Solar participates in a cluster called Solar Industry Platform. Do you know anything about that?**

No, I have not been involved with that.

**What universities and institutions do work with?**

We work with ECN, Philips and TNO.

**What is the cause for the weak PV cell market in the Netherlands?**

The Netherlands has always been advanced when it comes to research. But the market is weak indeed. I think energy conscience is lacking in the Netherlands. People are not really thinking ahead.

PV is a good investment even without subsidies. However it still seen as an add-on. When you buy a house you have limited budget and therefore you only buy things that are primary necessities. So of course PV does not come in the first place. In Germany and Italy for example there are subsidies and then the step to PV is easier. In these countries the governments realize the importance of being independent when it comes to energy, especially due to the fluctuating prices and dangers of nuclear power.

**Do you receive any subsidies as a company because you are involve in a sustainable technology?**

We did receive subsidies for research projects but I do not know if these subsidies are still going.

**Do you try to work towards Building integrated PV?**

That is a difficult market. The world sales volume of PV cells is per year about 15 Giga Watt only 10 MW per has been building integrated. BIPV usually has to do with building projects which take on average like 3 years that is too long for a cell manufacturing company like us.

There is a clear difference between BIPV and conventional PV seen project run trough times and profitability. However, it was and is always the intention hat PV shall find its way toward an integral part of a building. More and more people’s acceptance is rising to become energy autonomous. Still BIPV solutions stay a niche segment but also a very stable segment. We focus on the segment of residential rooftops; so, private houses, which offer better economical sustainability than the large scale project market who are closer to building integration.

**There are plans for a solar grade silicon factory called the Silicon Mine. Do you have contact with them?**

I think this factory is just a plan which is difficult to execute. When you produce silicon, which is an energy intensive production process, you need cheap energy. Energy in Limburg where the factory is planned is just too expensive. In Switzerland there is a company that I know of. But also in Norway, and there they get energy from Hydro power which is cheap and sustainable and therefore profitable. It is true that in the Netherlands we have great chemical companies but still looking at energy prices I do not expect this factory to take off.

**Amelie Veenstra, staff member Holland Solar, 8-8-2011**

**What kind of companies are members of Holland Solar?**

We have about 100 members for both PV and Solar thermal. Approximately 60 for PV and 40 for solar thermal. We represent the installation sector. We do not really have many members from the cell manufacturing sector. Solland Solar is a member but also inverter manufacturers like Mastervolt are members.

**How many PV installation companies are there in the Netherlands?**

There are around a few hundreds of them. Many small companies, which get their panels abroad and deliver them to customers. Many of them do not have the proper skills to install a safe and well functioning system. Therefore we initiated together with other parties an educational program for technicians to teach them the proper skills.

**Which solar technology gets most attention at your organization, is that PV or solar thermal?**

We represent both and we spend an equal amount of attention to both because we have an almost equal number of members for both technologies. But, what you can notice is that the market and government initiatives are mostly focused on PV.

**The initiatives of the government concerning PV are not very stimulating for the market, because of changing subsidies. What do you think about that?**

That is true. And that causes a lot of damage to the market. There is a constant stagnation. First because when some kind of subsidy is announced everybody waits for it to come into force until they install a PV system. Then subsidies are cancelled. Our members blame that to be the number one issue concerning PV in the Netherlands. They argue that no subsidy regulation at all is even better than this constant hesitation. The quality of the business is very high but the sales are disappointing.

**What are your lobby activities to improve the situation in the Netherlands?**

We lobby for subsidies, better regulations, we lobby for a better valuation of PV in the EPA which is a certification for energy performance and we work on quality assurance with the educational program and a guide book.

**How do you perform the lobbying activities?**

That depends on the issue. Usually we work with our members. We have contacts with the ministry of Economics, Agriculture and Innovation we provide them with information on how regulations affect our members and how to improve them. Sometimes we contact ministers or members of the parliament. We also have contacts with ECN which in their turn advise the government on energy issues. But we only have 100 members so we cannot have people working all over the Netherlands dealing with each issue. So we are small group working in a big world.

**Can you mention things that have been accomplished so far?**

We are now working on a Green Deal and making the process of installing a PV system and receiving subsidies much easier because now it is still unclear for consumers which steps are needed to install a PV system a receive subsidy for it. A Green Deal is an understanding between the government and companies involved in PV in which, without any financial support, the government makes it possible through regulations and adjustments that these companies can provide their products for attractive prices and realize big projects.

**SDE+ is for big systems only, why are small systems not supported anymore?**

That is because the current minister wants to achieve the CO2 goals with a few big steps. Bigger systems save costs. And, if you have to manage and monitor a lot of small systems, there is too much administrative work to be done.

**Do you know any other organizations that lobby for PV?**

There is ODE an organization for consumers. And ZPV, also a consumer organization.

**What has to change in the Netherlands, except for the subsidies, in order for PV to diffuse?**

The ministers always say that PV is too expensive, but that is not the case at all. That is being told by fossil fuel producers. A PV system is directly put on your house, if you think of it that way it is much cheaper. All the costs of energy produced with fossil fuels, which has to be transported etc, are much higher. Besides, some things like regulations regarding delivering energy to the grid are not clear not even to some members of the ministry that I talk to.

What you also hear is that there should be a better connection between the so called upstream and downstream market. Upstream are the cell and panel producers and downstream are the installer and advisors. We also work on improving those relationships.

**What about energy companies, I know they have to set off 3000 KWh, are they willing to do this or are they against this?**

Now they have set off 5000 KWh and they have the choice to set off more. But it differs very much some of them provide very clear information to their customers and some do not.

**Mark Pruissen, Product manager at Ubbink, 17-8-2011**

**Is it true that Ubbink has been the only panel manufacturer in the Netherlands until 2009?**

We have been the only panel manufacturers until 2010. That year a new panel manufacturer came to the market called Solar Modules Nederland.

**I have seen different news articles talking about Ubbink Solar to have gone bankrupt and some are saying it is not, so what was really going on in 2009?**

Econcern, a company active in sustainable energy projects went bankrupt. This company was the parent company of Ecostream which delivered solar panels. The mother company of Ubbink Solar Modules, Centrosolar, then decided to close the factory of Ubbink Solar Modules in Doesburg. That was because the factory was especially built to supply Ecostream. This factory was established in Doesburg in the building of Ubbink BV. They got the name Ubbink Solar Modules to become known among their target customers even though they were not really owned by Ubbink BV. Ubbink BV is involved in the building industry since 1896; and they decided to take over the machines and staff of Ubbink Solar Modules.

**How much of Ubbink's solar systems are sold in the Netherlands?**

We sell around 0.5 Mega Watt per year in the Netherlands. That is since 2009 when we took over the machines from Ubbink Solar Modules. I do not know the sales' numbers before that. So in total we installed 1 MW.

**Where did you buy the solar cells used in the panels?**

Until 2009 we exclusively bought our cells at Solland Solar. Now we also buy cells from Germany and Asia.

**Which parties do you work with in the Netherlands?**

We work together with parties from the installation sector and many wholesalers who buy systems from us.

**What are you R&D activities regarding solar panels?**

We are active in the building sector so we look for solutions to integrate the systems in rooftops for example. We do not really work on efficiency improvement of solar cells. We just buy our cells from companies that are known to deliver a good product quality.

**Do you know any collaborations between companies in the solar industry that aim to improve the situation in the Netherlands? Do you know the Solar Industry Platform?**

Holland Solar is an organization that tries to stimulate the market and the industry but I do not know any specific collaborations between companies. I also never heard of The Solar Industry Platform.

**Do you work with thin film solar cells?**

No, but we follow the developments. We focus on the house market and for this case c-Si modules are more suitable because of i.e. the higher efficiencies.

**Ubbink also started a company in Kenya, what are the activities there?**

Yes, cells that have been broken can be restored over there and sold. We actually have a relationship with Solland Solar on this project for the supply of broken cells. The electricity infrastructure is not very developed over there yet. When they can produce electricity in a decentralized manner they do not even need big expensive energy utilities anymore.

**How much are the global sales of Ubbink?**

That would be around 10 Mega Watt. In France, Germany, the Netherlands, Italy, so especially Europe.

**What needs to change to achieve a better diffusion of PV in the Netherlands?**

A subsidy would be a good stimulant. But, we gave up the idea of that ever happening. I think there needs to be a change in the mindsets starting with the government. They have to realize that within the existing current infrastructure there are a lot of opportunities for sustainable energy and PV.

**What is the return on investment for a system of Ubbink Solar?**

That is around 10 to 13 years. Depending also on the company that installs the system, so expensive companies have higher prices.

**How much is a system that delivers around 3,5 KWp ?**

That should be around 12,000 to 15,000 euro including VAT.