THE RISE AND FALL OF THE DUTCH PV INNOVATION SYSTEM
FROM 1970-2007 –
A SYSTEM FUNCTIONS ANALYSIS

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1. Introduction

It is widely recognised that the dominance of fossil fuel in the world energy system causes severe environmental problems, such as climate change. However, the diffusion and implementation of alternative technologies, such as renewable energy technologies, goes slowly. The new technology systems have to compete with an incumbent technological system that is locked-in the use of fossil fuel that benefits from long periods of experience, leading to high efficiency, low costs, optimal institutional arrangements, and many vested interests (Unruh 2000). These renewable energy technologies that can be labelled as radical innovation, are, in their early phases of development, still inefficient, crude, and badly tuned to the characteristics of the incumbent system and therefore diffusion goes slowly (Rosenberg 1976).

A relevant question, therefore, is how to break through the current situation of carbon lock-in, in order to accelerate the diffusion of renewable energy technologies in society. To answer this question, it is necessary to open the black box of carbon lock-in, and to analyse in a detailed manner how the development and diffusion of renewable energy sources takes place. Such an analysis should also allow us to pinpoint key mechanisms that block or induce the development process. Insight into these mechanisms is necessary to design policy arrangements that may efficiently deal with these inducement and blocking mechanisms, as to speed up the diffusion process of renewable energy sources.

In this paper we will analyse the evolution of photovoltaic technology (PV) in the Netherlands. The choice results from the gap between the high theoretical expectations of PV to contribute to a renewable energy supply, and the actual practice which shows that PV diffusion goes very slowly in the Netherlands. The research questions that will be answered in this paper are:

*What are the inducement and blocking mechanisms that have determined the evolution of PV in the Netherlands?*

*How can the diffusion of PV in the Netherlands be accelerated?*

2. Theory

For opening the black box and analysing the development and diffusion process of renewable energy sources, many different perspectives can be used. In this paper we focus on the perspective of Technological Innovation Systems (TIS), since this perspective includes many components – not just the relative price of the technology – but also actors, markets, networks, and institutions that have an influence on the development, diffusion and implementation of a specific technology (Carlsson and Stanckiewicz 1991). Generally, an emerging innovation system consists of a relative small number of agents and only a small number of institutions are aligned with the needs of the new technology. Thus, by applying the TIS approach it becomes possible to study dynamics and to come to a better understanding of what really takes place within innovation systems (Hekkert, Suurs et al. 2007). According to Carlsson and Stanckiewicz (1991) (p.94), a TIS is defined as:

"a network or networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilise technology."

This implies that there is a technological system for each technology and that each system is unique in its ability to develop and diffuse a new technology (Jacobsson and Johnson 2000).
A well functioning TIS is a requirement for the technology in question to be developed and widely diffused. The question remains, however, what determines whether or not a TIS functions well, other than defining success by the end result, i.e. a high level of technological diffusion?

Edquist (2004) states that “the main function – or the “overall function” of an innovation system is to pursue innovation processes, i.e., to develop, diffuse and use innovations” (Edquist 2004a) (p. 190). In order to determine whether a TIS functions well or not, the factors that influence the overall function – the development, diffusion, and use of innovation – need to be identified. Jacobsson and Johnson (2000) developed the concept of System Functions, where a system function is defined as “…a contribution of a component or a set of components to a system’s performance”. They state that a TIS may be described and analysed in terms of its ‘functional pattern’, i.e. how these functions have been served (Johnson and Jacobsson 2000). The functional pattern is mapped by studying the dynamics of each function separately as well as the interactions between the functions. The System Functions are related to the character of, and the interaction between, the components of an innovation system, i.e. agents (e.g. firms and other organisations), networks, and institutions, either specific to one TIS or ‘shared’ between a number of different systems (Edquist 2001).

Recently a number of studies have applied the System Functions approach, which has led to a number of System Functions lists in the literature (Edquist and Johnson 1997; Galli and Teubal 1997; Johnson 1998; Jacobsson and Johnson 2000; Liu and White 2001; Rickne 2001; Bergek 2002; Carlsson and Jacobsson 2004; Jacobsson and Bergek 2004; Hekkert, Suurs et al. 2007). This paper uses the recently developed list of System Functions at Utrecht University (Hekkert, Suurs et al. 2007; Negro 2007; Negro, Hekkert et al. 2007; Negro, Suurs et al. 2008) that will be applied to map the key activities in innovation systems, and to describe and explain the dynamics of a TIS. Below an overview of the System Functions used will be provided.

Function 1: Entrepreneurial Activities
The existence of entrepreneurs in innovation systems is of prime importance. Without entrepreneurs innovation would not take place and the innovation system would not even exist. The role of the entrepreneur is to turn the potential of new knowledge development, networks and markets into concrete action to generate and take advantage of business opportunities.

Function 2: Knowledge Development (learning)
Mechanisms of learning are at the heart of any innovation process. For instance, according to Lundvall: “the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning” (Lundvall 1992). Therefore, R&D and knowledge development are prerequisites within the innovation system. This function encompasses ‘learning by searching’ and ‘learning by doing’.

Function 3: Knowledge Diffusion through Networks
According to Carlsson and Stankiewicz (1991) the essential function of networks is the exchange of information. This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government, competitors and market. Here policy decisions (standards, long term targets) should be consistent with the latest technological insights and, at the same time, R&D agendas are likely to be affected by changing norms and values. For example if there is a strong focus by society on renewable energy it is likely that a shift in R&D portfolios occurs towards a higher share of renewable energy projects.
This way, network activity can be regarded as a precondition to ‘learning by interacting’. When user producer networks are concerned, it can also be regarded as ‘learning by using’.

Function 4: Guidance of the Search
The activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users fall under this system function. An example is the announcement of the policy goal to aim for a certain percentage of renewable energy in a future year. This grants a certain degree of legitimacy to the development of sustainable energy technologies and stimulates the mobilisation of resources for this development. Expectations are also included, as occasionally expectations can converge on a specific topic and generate a momentum for change in a specific direction.

Function 5: Market Formation
A new technology often has difficulties to compete with incumbent technologies, as is often the case for sustainable technologies. Therefore it is important to create protected spaces for new technologies. One possibility is the formation of temporary niche markets for specific applications of the technology (Schot, Hoogma et al. 1994). This can be done by governments but also by other agents in the innovation system. Another possibility is to create a temporary competitive advantage by favourable tax regimes or minimal consumption quotas, activities in the sphere of public policy.

Function 6: Resource Mobilisation
Resources, both financial and human, are necessary as a basic input to all the activities within the innovation system. Specifically for biomass technologies, the abundant availability of the biomass resource itself is also an underlying factor determining the success or failure of a project.

Function 7: Counteract Resistance to Change (Lobby Activities)
In order to develop well, a new technology has to become part of an incumbent regime, or has to even overthrow it. Parties with vested interests will often oppose this force of ‘creative destruction’. In that case, advocacy coalitions can function as a catalyst to create legitimacy for the new technology and to counteract resistance to change.

Both the individual fulfilment of each system function and the interaction dynamics between them are of importance. Positive interactions between System Functions could lead to a reinforcing dynamics within the TIS, setting off virtuous cycles that lead to the diffusion of a new technology. An example of a virtuous cycle that we expect to see regularly in the field of sustainable technology development is the following. The virtuous cycle starts with F4: ‘Guidance of the Search’. In this case, societal problems are identified and government goals are set to limit environmental damage. These goals legitimise the mobilisation of resources to finance R&D projects in search of solutions (F6), which in turn, is likely to lead to knowledge development (F2) and increased expectations about technological options (F4). Thus, the fulfilment of the individual functions is strengthened through interaction.

Vicious cycles are also possible, where a negative function fulfilment leads to reduced activities in relation to other System Functions, thereby slowing down or even stopping the progress.

Theme 5: FTA in Security and Sustainability
3. Methodology

The method used to map interaction patterns between System Functions is inspired by the process method called ‘Historical Event Analysis’ as used by Van de Ven and colleagues (Van de Ven, Polley et al. 1999; Poole, van de Ven et al. 2000). Stemming from organisational theory, the usual focus is on innovation projects in firms and firm networks; in our case, the analysis is applied to a TIS level (for a more extensive description of the methodology please consult (Negro 2007; Negro, Hekkert et al. 2007; Suurs and Hekkert 2007; Negro and Hekkert 2008; Negro, Hekkert et al. 2008; Negro, Suurs et al. 2008).

Basically, the approach consists of retrieving as many events as possible that have taken place in the innovation system using archive data, such as newspapers, magazines, reports and interviews. The events are stored in a database and classified into event categories. Each event category is allocated to one system function using a classification scheme (see Table 1).

### Table 1 Overview of allocation scheme

<table>
<thead>
<tr>
<th>Function 1: Entrepreneurial activities</th>
<th>Indicator</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project started</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Project stopped</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Organisations entering the market</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Organisations leaving the market</td>
<td>-1</td>
<td></td>
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</tbody>
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<tr>
<th>Function 2: Knowledge development</th>
<th>Indicator</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research projects</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Technological projects</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Development projects (demonstration + pilot plant)</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Desktop studies on the technology (future of PV + performance of PV-system)</td>
<td>+1</td>
<td></td>
</tr>
</tbody>
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<tr>
<th>Function 3: Knowledge diffusion through networks</th>
<th>Indicator</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workshops</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Conferences</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Reports</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Platform</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Roadmap</td>
<td>+1</td>
<td></td>
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<tr>
<th>Function 4: Guidance of the search</th>
<th>Indicator</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulations by the government (positive expectation on the PV-technology)</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Deficit of government regulations (negative expectation on the PV-technology)</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Specific tax regimes (positive expectation on the PV-technology)</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Deficit of tax regimes (negative expectation on the PV-technology)</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Positive opinions of experts</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Negative opinions of experts</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Positive expectations of experts</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Negative expectations of experts</td>
<td>-1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function 5: Market formation</th>
<th>Indicator</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation programmes</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Lack of regulation programmes</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Stimulation programmes</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Function 6: Resources mobilization</td>
<td>Lack of stimulation programmes</td>
<td>-1</td>
</tr>
<tr>
<td>-</td>
<td>Environmental standards</td>
<td>+1</td>
</tr>
<tr>
<td>-</td>
<td>Lack of environmental standards</td>
<td>-1</td>
</tr>
<tr>
<td>-</td>
<td>Specific favourable tax regimes</td>
<td>+1</td>
</tr>
<tr>
<td>-</td>
<td>Lack of favourable tax regimes</td>
<td>-1</td>
</tr>
</tbody>
</table>

| Function 7: Creation of legitimacy | Subsidies and investments of the technology | +1 |
| - | Lack of investments and subsidies | -1 |
| - | R&D subsidy programmes | +1 |
| - | Lack of R&D subsidy programmes | -1 |

| Context | General events about renewable energy, technology description, exogenous activities to TIS | No sign, no allocation |

The contribution of an event to the fulfilment of a system function may differ considerably from event to event. Some events have a positive contribution to the diffusion of the technology, while others contribute negatively as for instance an expression of disappointment, or the opposition of an important political group. This is indicated in the allocation scheme by +1 and -1. The balance between positive and negative events yields specific insights into the slowing down of system growth or into controversies emerging around the analysed technology.

The events are not weighted since the importance of an event is not known beforehand. Only after the construction of the narrative the importance of a specific 'watershed' event can be identified.

The final outcome of the process analysis is a narrative (storyline) of how the development of the TIS has changed over time and the role of the different System Functions within this development. In the narrative the focus is on extracting interaction patterns between System Functions. Based on the content of the events and their chronological order, we are able to deduce the effect of one event onto another and the order in which such events occurred. By observing reoccurring sequences of events we are able to identify interaction patterns between System Functions.
4. The Case of Dutch PV

4.1 Technology description

PV is the direct conversion of light into electricity, i.e. into an electric potential and a current. Solar cells are made of semiconductor material to achieve two basic tasks. First, the absorption of light energy to generate free charge carriers within the material, and second the separation of the negative and positive charge carriers to produce unidirectional electrical current through terminals that have a voltage difference between them (see Figure 2) (Corkish 2004).

![Diagram of the PV effect](image)

**Figure 1 Overview of the PV effect (Sinke 2007)**

There are various varieties of solar cell designs with different performance and cost features. The most current type is the crystalline silicon (c-Si) cell as it is reliable and highly efficient. However their costs are high due to the need for purity and the use of large amounts of material. In order to reduce the costs other types of cells have been developed in the past 20 years, which can be labelled as second and third generation PV technology (Corkish 2004; Van_Sark, Brandsen et al. 2007). However, only the first generation cells are commercially available yet, and will be the technology analysed in this paper, if not mentioned otherwise.
4.2 Historical overview of PV from 1970-2008

In this section a chronological description of the events that took place in the PV trajectory is presented. The description will be subdivided into different year periods. The end of each period is chosen on the basis of change in activities or key events, therefore not all periods are equal in length. The symbols F1-F7 refer to the seven System Functions as described in chapter 2.

4.2.1 The beginning of PV in the Netherlands

The awareness of the finite amount of fossil fuels has increased since the oil crises in the seventies. The Dutch government guides the search by publishing two ‘Energy White Papers’ in 1974 and in 1979, which triggers the expectations of entrepreneurs, who then carry out research. The positive results lead to the setup of lobby activities by ISES-NL and dr. Giling for the expansion of fundamental research on PV and its acceptance as a renewable energy source. At the end of 1984 a coordinated programme starts for fundamental PV research, the so-called ISES-programme. The ISES-programme has two research themes concerning PV, one on crystalline gallium arsenide (GaAs) cells that have the potential of high efficiency (35-40%) and the other on amorphous silicon (a-Si) with low production costs and an efficiency of potentially 15-20% (DE 1987; Verbong, van Selm et al. 2001).

In 1986 the NOZ-PV programme (5 million euros) is started with the aim to follow international activities concerning PV by maintaining expertise on several specific areas that are already present in the Netherlands. Another goal is also to promote the development of PV conversion concerning the future energy provision in the Netherlands (DE 1987; Verbong, van Selm et al. 2001).

Towards the end of the eighties the government makes an important contribution in spite of its doubts (whether PV technology would not be more appropriate for sunny countries and decentralised energy systems). They implement the ‘Support Regulation Energy Savings and Flow Energy’ (SES) in 1988 and will renew it in 1991. This regulation is directed towards autonomous PV systems including a special budget, where 40% of the purchase costs of a system are compensated (N&M 1990; DE 1991). Another interesting subsidy programme starts in 1989, the ‘Community Energy Saving Approach’ (GEA). The main aim of this programme is to stimulate local authorities to implement energy efficiency measures and stimulate the use of renewable techniques. The programme is adjusted in the beginning of the nineties and stops providing financial support in 1995, but continues with advising (DE 1997a).

Until this time the assumption is that a breakthrough of PV could only be reached by technological developments, but besides this also market stimulation is needed. Therefore the attention shifts from mainly research on improving efficiency of cells to both research and applications. For these reasons a substantial part of the budget (about 9 million euros) is reserved for system research in the second NOZ-PV (1990-1994) (DE 1992; DE 1993; Verbong, van Selm et al. 2001). Also, in 1990 the ‘White Paper on Energy Savings’1 is published. The goal is that in 2010 2 PJ of fossil fuels have to be replaced by using PV, which is equal to 240 MWp of PV modules. This is the first time that an aim for PV is formulated, resulting from to the fear of elevated oil prices (Andriessen 1993; EnergieNed 2000; Verbong, van Selm et al. 2001). The awareness about the environment, finite nature and dependency of fossil fuels increases even more and the framework of the ‘National Environmental Plan’ (NMP) inspires the energy distribution companies to publish the first

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1 in Dutch: Nota Energiebesparing
‘Environmental Action Plan’ (MAP-1) in 1991. With this agreement they dedicate themselves to take the social responsibility by providing a substantial contribution to a sustainable and environment friendly energy supply (EnergieNed 2000; Verbong, van Selm et al. 2001).

Thus the government guides the search by introducing the above mentioned frameworks and a specific programme on PV, such as NOZ-PV. This triggers the expectations of entrepreneurs who then carry out research to provide a professional PV technology. The ‘Energy research Centre of the Netherlands’ (ECN) starts to cooperate with a large number of parties from the Netherlands as well as from foreign countries, originating from both the research world and the industrial sector. These research groups have an important role during the development of PV system. In 1994, ECN and R&S produce an industrial module with an efficiency of 16%, and R&S starts a pilot production line for multicrystalline silicon PV. An important position by the Netherlands is achieved worldwide with these technological improvements (DE 1994a; E&M 1994a). In addition some research projects are set up by several Dutch Universities, where PV is placed on house roofs (e.g. Caticum, Heerhugowaard, Barendrecht) (Schoen 2001; Verbong, van Selm et al. 2001). These projects not only lead to knowledge development and more financial resources, but also guide the search by highlighting the importance of this technology.

In this period positive results from research (F2) trigger lobby activities (F7) for better institutional conditions (F4), triggering entrepreneurs to set up the first projects (F1). Thus, here we observe a first build-up of a virtuous cycle.

4.2.2 PV grows further in the Netherlands during the last half of the nineties

However, a turning point occurs in 1994 when the government wants to stop the SES subsidies on small scale PV projects. However, after strong criticism from the environmental movement, the government agrees to end the SES gradually in 1995 instead of abruptly (N&M 1993; DE 1994). In order to compensate for the vanished SES subsidy, several alternative financial stimulations are launched. A levy on usage of electricity (PV) and natural gas is established, called the ‘Regulating Energy Taxes’ (REB) (E&M 1995). Several other tax measures are introduced as well, where sustainable energy and energy saving are stimulated fiscally, like the ‘Free Debit Environment Investments’ (VAMIL) and ‘Energy Investment Allowance’ (EIA) programme (SenterNovem; DE 1996). In addition several programmes such as ‘the Green Projects’, the ‘Energy Savings Funds’ (EBF), the ‘Decision Subsidy Energy programmes’ (BSE) and later on the ‘Economy, Ecology en Technology’ (EET) programme are started as well (milieuloket; sunergy.thrijswijk.nl; E&M 1995; DE 1997). Furthermore, after the end of the NOZ-PV programme (1990-1994), where the focus was on research and development, a new NOZ-PV (1997-2000) is started in 1997, which is more market oriented. The main aim of the programme is the realisation of conditions and the diminishment of the bottlenecks for the large-scale implementation of solar cells in Dutch energy provision in the twenty first century (DE 1995b; Roos and Blom 2001).

In the second half of the nineties PV forms the largest expenditure post in the field of research and implementation of renewable energy in the Netherlands (Verbong, van Selm et al. 2001). This leads to that the PV market starts to evolve (EnergieVerslag 1997). In 1997, R&S becomes Shell Solar Energy BV and opens a new production line of PV cells with a capacity of 2.5 MWp per year with the intention of expanding within a period of five years to approximately 20 MWp per year (TW 1997a; DE 1997b; TW 1997b). In addition some energy distribution companies are active in the introduction of PV on the market such as NUON, PNEM and REMU (DE 1995; E&M 1998; Mierlo 2006). Large-scale projects are set up in this period by applying the PV technology on house roofs in the district of Nieuw Sloten in Amsterdam, the district Nieuwland in Amersfoort and the HAL project (EnergieVerslag 1997; Mierlo 2006). Other successful projects are realised within the programmes of Greenpeace, “Solaris” and “PV GO!”, where they installed PV modules on 3000 houses (DE 2000; Schoen
All these projects aim to gain experience from which future project could learn, in order to increase the diffusion of PV in the Netherlands. Furthermore the research in the Netherlands focuses on several items which are closely linked, namely cost reductions, performance improvements and integration into buildings.

The conclusion can be made that the nineties are very successful with respect to the development and diffusion of PV in the Netherlands. The most crucial factor is that 20 years ago PV was no option for the Netherlands, but by now it is the most promising option of renewable energy (Verbong, van Selin et al. 2001). However, beside these positive sounds there are also negative ones. In comparison with other technologies PV remains expensive and the forecasts over the years in which PV would become economically profitable, become more and more pessimistic.

This period is marked by the set up of large-scale projects by applying the PV technology (F1). These projects not only lead to knowledge development (F2) and more financial resources (F6), but also guide the search by highlighting the importance of this technology (F4). The previous virtuous cycle continues in this period where financial support (F6) through programmes and funds are allocated to PV, which triggers a cautious growth of the Dutch PV market (F5).

4.2.3 The support of PV changed in the Netherlands during the first years of the twenty first century

In the beginning of the century a large political shift takes place in the Lower Chamber. A coalition agreement is implemented where from 2003 every year 500 billion Euros have to be saved on energy and environmental subsidies. The reason for this is the great amount of financial stimulations for PV and a lot of free-riding, as some projects obtain financial support from several programmes simultaneously (PV-Nieuwsbrieven 2002/2003).

In addition, on the first of July 2001, the green energy market is liberalised (DE 2001a). This is one of the most important events that made 2001 a turbulent year for PV. From this moment on PV has to compete on a free market with cheaper renewable energy options. Nonetheless, there is support from environmental organisations (Greenpeace, WWF) and from energy distribution companies (Nuon and Eneco Energy), which introduce extra subsidy on PV. Together they reinforce the importance of the image of solar energy in the liberalised green energy market (Swens and Heul 2002). In addition, since the Ministry of Economic Affairs has a decreasing coordinating role the urge is felt to get better organised and the PV industry association called ‘The Dutch Renewable Energy Association’, ‘DE Koepel’ of Holland Solar is restarted. In 2003, this evolves into the most important solar platform in the Netherlands (dekoepel.org). In addition the market for small PV systems is boosted by dedicated campaigns of municipalities, some of them offering extra subsidies. Some examples are: ZonZeker, (Province of Groningen and Essent) to stimulate consumers to buy PV and boilers (DE 2001c) and ‘More roofs under the sun’ (Novem) stimulating house building agencies to include PV (DE 2004b). An important project set up in this period is the PV system on the roof of the ‘Floriade’, which is the largest roof integrated PV system of the world (DE 2002a).

2 At the beginning of the century 6 programmes were active: ‘Energy Contribution Regulation’ (EPR), ‘Energy Performance Advice’ (EPA), ‘Energy Investment Non Profit sector’ (EINP) ‘New Energy Research’ (NEO), ‘Sustainable Energy in the Netherlands’ (DEN), and ‘Environmental Quality of the Electricity Production’ (MEP) (SenterNovem; sunergy.thrijswijk.nl; Haas 2002; Swens and Heul 2003; DE 2003a). Most programmes were of short duration and ended also in this period due to the coalition agreement.

3 Worlds horticulture exposition in the Netherlands
However, throughout the years the trust decreases due to the unreliable behaviour of the government with respect to the starting and stopping of programmes, which leads to less financial support and a lack of market formation, so that little prospect is provided for entrepreneurs to set up new large scale projects.

For the industry it is a turbulent period as well. In December 2002 Shell Solar announces the closing of the PV plant in Helmond, because they wanted to concentrate their activities in North-America, Germany and Portugal (DE 2002b; DE 2004). With this closure in Helmond the production of solar panels is decreased to practically zero in the Netherlands.

This period is marked by major institutional changes, i.e. liberalisation of the market and a lack of guidance by the government (-F4). This results in disappointments and lack of trust within the PV sectors (-F7), as industry is stopping activities in the Netherlands due to unfavourable institutional conditions and entrepreneurs are reluctant to take any risks (-F1). This sets forth a sequence of negative events that reinforce each other, resulting in a vicious cycle, and finally in the collapse of the Dutch PV market.

4.2.4 The fall of PV in the Netherlands towards the first half of the twenty first century

On top of the already decreasing activities in the PV sector, in 2003, the EPR is suddenly ended and the utility subsidies look dramatically for the Netherlands. However new opportunities arise and a wide consultation amongst energy research, industry and policy professionals show the need for programmes that contribute to the future Dutch energy production and to increase the level of expertise in the Netherlands. During the first half of 2004, the Ministry of Economic Affairs and SenterNovem give ear to this call and develop a new set of energy research and technology development programmes. These programmes cover a full range of renewable energy technologies where PV is one of the priority areas (Heppener, Boomsma et al. 2002). The MEP and EIA are also available for the implementation of PV in the market during this period (SenterNovem; Swens and Heul 2007) and in 2005 net-metering becomes available (eere.energy.gov).

Simultaneously the worldwide market begins to grow, and the Dutch entrepreneurs notice this upcoming market and try to be one of the leading countries. A boost of successful activities takes place in 2004, in spite of high risks in the fast developing sector. There are sufficient entrepreneurs active for solar cells like Solland Solar, Scheuten Solar, NUON-Helianthos, RGS Development, Ubbink Solar, as well as for BOS products, such as Econcern, Oskomera and Mastervolt. However, all these entrepreneurs concentrate on the export market, such as Germany and Spain, because of the lack of a market and financial incentives in the Netherlands. This shift towards an export market leads to that the installed capacity of PV per year in the Netherlands drops from 2003 with 19.3 MW to almost 0 within 3 years (see Figure below).


5 Balance-of-system products

THEME 5: FTA IN SECURITY AND SUSTAINABILITY
Nonetheless, during this period the research continues and focuses on cost reduction and quality improvement of polycrystalline silicon cells and thin film silicon cells. The research and development in the Netherlands is mainly relying on European support programmes\textsuperscript{6} (SenterNovem; DE 2003b). The activities concerning the EOS programme are internationally connected through the participation of SenterNovem in the ‘Photovoltaic European Research Area Network’ (PV-ERA-NET). Beside these European support programmes there is also the Joint Solar Programme with only Dutch actors (fom.nl; TW 2004).

Nonetheless the export driven activities, Holland Solar believes that solar energy could still contribute to the renewable energy supply of the Netherlands. For this reason a ‘Roadmap Solar Energy’ was set up, where the vision on the future and also the steps for further market development are described (Bode 2005). A second roadmap is developed in the PV Catapult project with EPIA and Ecofys constructs a European Building Integrated PV (BIPV) Roadmap (PhotonInternational 2005b).

However, without notice on the 18th of August 2006 the Ministry of Economic Affairs ends the MEP subsidy immediately. They argue that the aim of 9% production of sustainable electricity in 2010 could also be achieved without the stimulation regulation (Energie+ 2006). This news comes as a shock to the renewable energy sector and the image of an unreliable government is fortified again.

The most outstanding event in this period is the drop of PV installed in 2004 in comparison to 2003 (-F1) (see Figure 2). The reasons being unfavourable institutional conditions (-F4), no Dutch market (-F5) but a growing international market. This resulted in a shift of interests towards export activities instead of further developing the Dutch market. Thus, the previous vicious cycle continues in this period.

\textsuperscript{6} Crystal Clear, European PV Technology Platform, FullSpectrum, Performance, PV-catapult, PV Policy Group, PVSAT-2, and PV-TRAC (Photovoltaic Technology Research Advisory Council).
4.2.5 Revival of PV in the Netherlands?

On 22 February 2007 the cabinet launched a new coalition agreement (Coalitieakkoord 2007; Swens and Heul 2007; Bundy 2008). As part of the Dutch energy transition policy a ‘Transition platform for renewable electricity supply’ (TP-DEV) was established to initiate the transition to a sustainable electricity supply. The platform was initiated in 2006 with the motive to evaluate the existing policy concerning PV, to formulate recommendations for the government on desired and required legislation and to realise the above mentioned targets. The Dutch Ministry of Economic Affairs, the Dutch research and technology development institutes and the Dutch PV industry participate in this platform (Energie+ 2007; Sinke 2007; Sinke, Bokhoven et al. 2007)

Nonetheless the sudden stop of the MEP regulation, activities continue within the Dutch PV sector and several solar companies set up plants. A ‘European Science and Business Park’ between Heerlen (The Netherlands) and Aachen (Germany), called Avantis, is set up. The purpose of Avantis is to give new technologies the space they need to develop and to enable and strengthen synergies between research, development and international management. In addition, the location offers excellent opportunities for entrepreneurs and investors, due to the advantage of obtaining subsidy from two countries (MilieuMagazine 2001).

Other solar companies that are active in the Netherlands are Scheuten Solar which chooses for Venlo instead of the Avantis park to build their Sunrise pilot plant (ScheutenSolar 2007) and Advanced Photovoltaic Applications BV (APA), established in Bleiswijk (Leewarden). It is a spin-off of the companies Advanced Surface Technology BV (AST), Nano Energy Europe (NEE) and SolarTotal BV. APA started in this period with the preparation for a small CIS factory based on spray deposition technique developed by AST (noordnederlandpiekt.nl; FEM.Business 2007).

In this period the research activities continue on lowering the price of PV in order to be able to compete with the conventional energy, thus to enable large-scale implementation. Therefore, FESTpv is set up by the European PV industry (Solland Solar, TSM, Scheuten Solar, Econcern, Rena, Applied Materials Schutweterland, Ersol wafers, Pillar and Vesuvius) together with ECN and the International Solar Energy Research Centre (ISC) in Konstanz, Germany. The aim is to develop cheaper solar cells by improving the material quality and production process for silicon. The research centre which is planned to open in the spring of 2009 will also be located on the Avantis park (DeLimburger 2007; ECN 2007).

Finally, it is difficult to make predictions about the future, but it seems to be the beginning of a promising future for PV in the Netherlands. The Dutch environment appears to become more favourable for research and projects due to the EOS programme (F4). The policy focuses on research and development (F2), especially on the technology development for more cost efficient systems in the near future. A positive aspect is the increased international orientation, allowing more international interaction, exchange of knowledge and experience (F3).

A new impulse for investment in renewable energy will be generated with the new subsidy programme ‘Stimulation of Renewable Energy production’ (SDE) which started in April 2008 (F5). A special budget is allocated to PV to prepare the Dutch market for the large-scale implementation in the near future (F6). It is expected that in 2008 a market between 10 and 20 MW will be initiated. These are positive sounds, but five years ago a capacity of 19.3 MW was already reached.

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7 The aim is to make great steps in transforming the energy supply into one of the most sustainable and efficient in Europe by 2020. The Dutch government pledges to an annual energy saving of 2%, an increase in the share of sustainable energy to 20% by 2020 and a 30% reduction in greenhouse gas emissions by 2020 relative to 1990.

8 In Dutch: ‘Transitieplatform Duurzame Elektriciteitsvoorziening’
5. Conclusion

The first purpose of this paper was to analyse the evolution of PV in the Netherlands and to identify the barriers and carriers that contributed to it. The second purpose is to provide recommendations about intervention strategies on how to accelerate the diffusion of PV in the Netherlands.

From the narrative we observed a build-up of several System Functions from 1970 until the turn of the century. The trigger of the virtuous cycles starts with guidance of the search (F4), triggering knowledge creation (F2), entrepreneurial activities (F1), resource mobilisation (F6), and market formation (F5), which leads to a build-up of a small Dutch PV market (F5). However, in the beginning of the twenty first century, a change in institutional conditions (i.e. the coalition agreement) triggers a vicious cycle, where negative guidance against PV (-F4) hinders any market formation (-F5), investments (-F6) or lobbies to occur (-F7) and finally leading to the discontinuation of entrepreneurial activities (-F1). These negative events reinforce each other and result in less activities being carried out. The amount of projects considerably decreases, as well as the installed capacity of PV per year, which drops from 2003 with 19MW to 3.2 MW in 2004, and decreases further to 2 MW in 2005 and 0.3 MW in 2006; Ever since PV has failed to become diffused on a large scale in the Netherlands.

From the interactions of the past years can be learned that in spite of the fact that most of the System Functions are fulfilled, interact with each other and that the technology is proven as reliable, the PV technology will not break through as long as there is no secure market formation and consistent government guidance. These are the two main System Functions that need to be triggered in order to restore a positive cycle that will help to diffuse PV. In order to fulfill the System Function ‘Guidance of the Search’, regulations should be formulated, starting from a common vision. Government and market parties should formulate this vision together9, in order for all actors to feel responsible and dedicated to it. Furthermore it is important to give PV a clear role in the Dutch energy supply system, together with a tailored market introduction, and guarding the quality of feedbacks from learning experiences. Visibility of successful results and projects will lead to enthusiasm of buyers (market formation) and investors (resources). In addition cooperation and knowledge diffusion should be stimulated. If these processes are triggered entrepreneurs will be attracted to enter the Dutch market rather than the international one and provide more resources. In this way the System Functions will reinforce each other and contribute to the build-up of a Dutch PV innovation system, which will increase the chance of diffusion and implementation of PV in the Netherlands, as a large and good knowledge base and expertise is already present in the Netherlands.

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9 There is already a roadmap by Holland Solar and the PDEV, but the government does not feel much for it.
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Summary
The current situation of large fossil fuels dependency and the hampered breakthrough of renewable energy sources and associated technologies can be described in the term 'carbon lock-in' (Unruh 2000). Renewable energy technologies have to overcome considerable barriers in order to breakthrough in an established system such as the fossil fuel system. In order to analyse the development and diffusion process of renewable energies, not only the technical and economical aspects have to be studied, but also the social system that influences the development, diffusion and implementation of renewable energy technologies. This social system is called the Technological Innovation System (TIS). Within this system all actors, institutions and organisations are included that influence the development and implementation of a new technology. However by only analysing the structural components of a system, not much insight is created in the underlying factors that make new technologies successful or not. Therefore, the ‘System Functions’ of a TIS will be identified, i.e. those are all the activities that take place within an TIS; Our assumption is that the System Functions are necessary to build up a well functioning innovation system in order to diffuse new technologies. By identifying which System Functions are present or not, appropriate strategies can than be designed to help overcome the barriers. The System Functions that are used in this paper are based on an extensive literature search and tested in several empirical case studies (Negro 2007; Negro, Hekkert et al. 2007; Suurs and Hekkert 2007; Negro and Hekkert 2008; Negro, Hekkert et al. 2008; Negro, Suurs et al. 2008).

F1: Entrepreneurial Activities
F2: Knowledge Development
F3: Knowledge Diffusion
F4: Guidance of the Search
F5: Market Formation
F6: Resource Mobilisation
F7: Counteract Resistance to Change

In this paper we will use the insights of an empirical case studies, the development and diffusion of photovoltaic (PV) energy in the Netherlands from 1970-2007, to better understand what the functioning of an innovation system is and to identify barriers that need to be overcome to make an emerging technology, such as PV, successful.

From the results we observe that there are two main System Functions that need to be triggered in order to help the diffusion of PV. In order to fulfil the System Function ‘Guidance of the Search’, regulations should be formulated, starting from a common vision. Government and market parties should formulate this vision together, in order for all actors to feel responsible and dedicated to it. Furthermore it is important to give PV a clear role in the Dutch energy supply system, together with a tailored market introduction, and guarding the quality of feedbacks from learning experiences. Visibility of successful results and projects will lead to enthusiasm of buyers (market formation) and investors (resources). In addition cooperation and knowledge diffusion should be stimulated. If these processes are triggered entrepreneurs will be attracted to enter the Dutch market rather than the international one and provide more resources. In this way the System Functions will reinforce each other and contribute to the build-up of a Dutch PV innovation system, which will increase the chance of diffusion and implementation of PV in the Netherlands, as a large and good knowledge base and expertise is already present in the Netherlands.