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Understanding innovation system build up: The rise and fall of the Dutch PV Innovation System

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Abstract

Renewable energy technologies have a hard time to break through in the existing energy regime. In this paper we focus on analysing the mechanisms behind this problematic technology diffusion. We take the theoretical perspective of innovation system dynamics and apply this to photovoltaic solar energy technology (PV) in the Netherlands. The reason for this is that there is a long history of policy efforts in The Netherlands to stimulate PV but results in terms of diffusion of PV panels is disappointingly low, which clearly constitutes a case of slow diffusion. The history of the development of the PV innovation system is analysed in terms of seven key processes that are essential for the build up of innovation systems. We show that the processes related to knowledge development are very stable but that large fluctuations are present in the processes related to 'guidance of the search' and 'market formation'. Surprisingly, entrepreneurial activities are not too much affected by fluctuating market formation activities. We relate this to market formation in neighbouring countries and discuss the theoretical implications for the technological innovation system framework.

Keywords: *Photovoltaic, Innovation system dynamics, Motors of Change*

Introduction

It is widely recognised that the dominance of fossil fuels 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 that would at least partly solve this problem, proceeds slowly. New technologies have to compete with an incumbent technological system that is locked-in the use of fossil fuel (carbon lock-in) and 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 (RET) on the other hand are in their early phases of development and therefore still inefficient and badly adapted to the function they need to fulfil in society. This makes rapid diffusion a very difficult process (Rosenberg 1976).

A relevant question, therefore, is how to break through the lock-in situation, and create a situation where renewable energy is widely used 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 this development process. Insight into these mechanisms is necessary to design policy arrangements that can efficiently deal with these blocking and inducement mechanisms, in order to speed up the diffusion process of renewable energy technologies.

For opening the black box and analysing the development and diffusion process of renewable energy technologies, many different perspectives can be used. In this paper we use the framework of Technological Innovation System (TIS). In the last years this framework has been developed and nowadays it is often applied to analyse technological transformation processes (Carlsson and Jacobsson 2004; Alkemade, Kleinschmidt et al. 2007; Hekkert, Suurs et al. 2007; Negro, Hekkert et al. 2007; Suurs and Hekkert 2007; Bergek, Hekkert et al. 2008; Hekkert and Negro 2008; Jacobsson 2008; Kamp 2008; Negro and Hekkert 2008). The strength of the framework is that it takes a system perspective to explain how different structural components of the innovation system (technology, actors, networks and institutions) influence the development and diffusion of a specific technology. The influence of these components can analytically be split up in blocking and inducement mechanisms.

In this paper the specific technology that will be analysed is photovoltaic solar energy technology (PV) in the Netherlands. The reason for this is that there is a long history of policy efforts in The Netherlands to stimulate PV but results in terms of diffusion of PV panels is disappointingly low, which clearly constitutes a case of slow diffusion. By studying this case, we can learn what went wrong and use these insights to prevent similar tragedies in other countries and/or for other technologies. Therefore, the research questions that will be answered in this paper are:

1) *What are the blocking and inducement mechanisms that have determined the build up of the PV innovation system in the Netherlands?*
2) *How can the diffusion of PV in the Netherlands be accelerated?*

In the next section the theoretical framework will be described in more detail. Section 3 provides insights in the methodology used in order to identify the barriers or triggers for the development of PV. In section 4 the development, diffusion and implementation of PV technology in the Netherlands will be elaborated and analysed. Section 5 will conclude this paper by answering the above mentioned research questions, discuss some theoretical and policy implications, and provide recommendations on how to accelerate the diffusion of PV.

The functioning of Technological innovation systems

The theoretical framework used to analyse the evolution of PV in the Netherlands is that of an emerging Technological Innovation System (TIS).

A TIS is defined to comprise a set of actors and institutions whose actions and interactions contribute to the development and diffusion of a new technology. Institutions are in this case the rules of the game and consist of formal institutions (e.g., regulations) and informal institutions (e.g., values, expectations). When a TIS starts to emerge very few actors are involved who put efforts in developing the technology in question. When time goes by and success occurs the TIS is likely to grow in number of actors, strength of networks and in terms of institutions aligned in order to support the new technology (Hekkert, Suurs et al. 2007; van Sark, Brandsen et al. 2007; Hekkert and Negro 2008). This is called the formative phase of a TIS (Jacobsson 2008).

Recent studies have shown great progress in understanding this formative phase of a TIS (Hekkert, Suurs et al. 2007; Hekkert and Negro 2008; Jacobsson 2008). The basic conclusion that follows from these studies is that a number of key processes need to take place in a TIS in order for the system to grow in terms of structural elements (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). A well functioning TIS in the formative stage, is a growing TIS and a requirement for the technology in question to be developed and widely diffused. The key activities are indicators for a well functioning innovation system and are often labelled as functions of innovation system (or system functions). Based on Hekkert et al (2007) we discern the following system functions.

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 a 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. For example, for PV, the abundant availability of silicon might be an underlying factor determining the success or failure of a project (van Sark, Brandsen et al. 2007).

Function 7: Creation of legitimacy / counteract resistance to change

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. Earlier research has shown that positive interactions between system functions leads to reinforcing dynamics within the TIS, setting off *virtuous cycles* (positive feedback loops) that lead to an accelerated build up of the TIS in question. These reinforcing dynamics are labelled ‘motors of change’ (Suurs and Hekkert 2007).

Vicious cycles (negative feedback loops) are also possible, where a negative function fulfilment leads to reduced activities in other system functions, thereby slowing down the build up of the TIS or even stopping the progress.

So far we have stressed the type of processes that seem to be important to successfully build up innovation systems in the formative stage. Additionally, it would also be interesting to understand who is involved in these processes. Garud and Ahlstrom (1997) have made a distinction between ‘insiders’ and ‘outsiders’ to assess health care technologies, but the same concept could be applied to assess renewable energy technologies. Insiders are those actors that are strongly devoted to make a new technology successful. They strongly believe in the technology and their economic success is to a great extent dependent on the success of the technology in question. Outsiders on the other hand have a much more neutral stance towards the technology. However, when they see good chances for the technology in question, they engage and thereby contribute to the build up of the innovation system. The engagement of outsiders is of crucial importance for the build up since these actors bring in additional and necessary resources like knowledge, financial means and power to change institutional structures. In Suurs and Hekkert (2007) this actor model is applied to study the formative phase of a number of different innovation systems (biomass gasification, biofuels, hydrogen fuel cells and automotive natural gas). This work showed that most key activities in the early phase of an emerging TIS are initiated by insiders. When they are successful in drawing in outsiders and keeping them ‘inside’, the success chances for the technology in question increase rapidly.

In this article we will analyse the development of the PV TIS in The Netherlands by applying the functions of innovation systems approach to find the resulting motors of change. Moreover, we look into the role of insiders and outsiders in order to draw lessons from these innovation system dynamics.

Methodology

The method used to map interaction patterns between System Functions is inspired by the process method 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 we refer to (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

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

	Negative opinions of experts	-1
	Positive expectations of experts	+1
	Negative expectations of experts	-1
Function 5: Market formation	Regulation programmes	+1
	Lack of regulation programmes	-1
	Stimulation programmes	+1
	Lack of stimulation programmes	-1
	Environmental standards	+1
	Lack of environmental standards	-1
	Specific favourable tax regimes	+1
	Lack of favourable tax regimes	-1
Function 6: Resources mobilization	Subsidies for and investments in the technology	+1
	Lack of subsidies and investments	-1
	R&D subsidy programmes	+1
	Lack of R&D subsidy programmes	-1
Function 7: Creation of legitimacy	The technology is promoted by organisations, government (awards, brochures, competitions)	+1
	Lack of promotion by organisations, government (awards, brochures, competitions)	-1
	Lobby activities for the technology	+1
	Lobby activities against the technology	-1
	Positive opinions of experts branch organisations	+1
	Negative opinions of experts branch organisations	-1
Context	General events about renewable energy, technology description, exogenous activities to TIS	No sign (0), 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, such as the opening of a large-scale building integrated PV project, 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 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 motors of change. 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 motors of change.

The Case of Dutch PV

Technology description

The photovoltaic effect, discovered in 1839, entails the direct conversion of light into electrical power, by the generation and separation of free charge carriers (electrons, holes) (Butti and Perlin 1980). Figure 1 depicts the most common device structure: a p-n junction (Green 1982). This figure shows a thin n-type doped semiconductor on top of a thick p-type one. The semiconductor, usually silicon, is essential in absorption of light energy to generate free charge carriers within the material. The device design is needed to separate negative and positive charge carriers to produce unidirectional electrical current through terminals (front and back contact) thereby minimising carrier recombination, The voltage between the terminals is set such to generate optimal power.

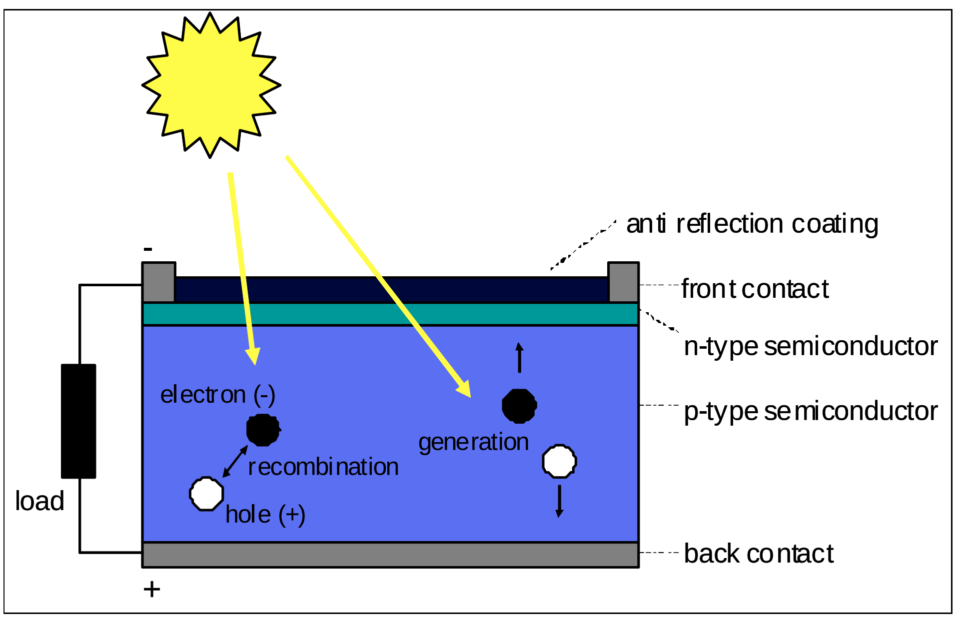

Figure 1 Typical solar cell structure: a thin n-type semiconductor connects with a p-type semiconductor to optimally generate and separate charge carriers upon light absorption. Charge collection is via front and back contact, which are externally connected to a load.

There are various varieties of solar cell designs with different performance and cost features. The so-called first generation technology uses the crystalline silicon (c-Si) cell. It is reliable and typical conversion efficiencies are 15-20%, while costs are high due to the need of large amounts of very pure silicon. In order to reduce the costs other types of cells have been developed in the past decades, which are generally referred to as second and third generation PV technology (Green 2003; Green 2005)   Second generation PV technology denotes the use of thin-films, and is aiming at reaching low-cost devices with acceptable efficiencies. Amorphous silicon is one example, and cells reach efficiencies around 10%. Other thin film materials classes, such as cadmium telluride approach efficiency values of c-Si technology, The dye-sensitized solar cell is another example of second generation PV technology: it is a photo electrochemical solar cell, which uses a liquid electrolyte or other ion-conducting phase as a charge transport medium. Third generation solar cells are mostly existing in the research laboratories only. As c-Si technology is dominating the present market, it will be the technology analysed in this paper, if not mentioned otherwise.

Historical overview of PV in the Netherlands 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 of equal length. The symbols F1-F7 refer to the seven System Functions as described in section 2.

The beginning of PV in the Netherlands (1970-1993)

The key events that triggered the start of a PV innovation system are the oil crises in the seventies. Dutch policy makers became aware that the Dutch economy is too dependent on fossil fuels and that a diversification strategy was necessary. The Dutch government publishes two ‘Energy White Papers’ in 1974 and in 1979 that clearly state the need for alternative energy sources (F4). In the energy research community these signals are picked up and research projects start to explore PV technology. The research leads to positive outcomes (F2) which influence the scientists to lobby for the expansion of fundamental research on PV and its acceptance as a renewable energy source (F7). The Dutch government is susceptible to this lobby and at the end of 1984 a coordinated programme starts for fundamental PV research at three Dutch universities, the so-called ISES-programme, as Dutch members of the International Solar Energy Society (ISES) play a key role in this (F4) (DE 1987; Verbong, van Selm et al. 2001). 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). Over the years the popularity of PV within the government continues to grow and in their budgets the Ministry of Economic Affairs pays more attention to research on PV conversion (Blok 1985). Thus, in 1986 the National Research Programme on PV[1] (with a budget of 2.7 million Euros) is started (F2), aiming to follow international activities concerning PV by building up and 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).

In 1983 'Holland Solar' is founded, the Dutch Solar Trade Association, which will become a main sparring partner for the Ministry of Economic Affairs. The members of the association are companies or organisations active in the field of solar thermal energy and/or photovoltaic solar energy for small - and large-scale applications. Holland Solar members cover more than 95% of the market for solar thermal energy systems in the Netherlands. Additionally architects, energy companies and consultants working in the solar thermal field are members as well (Reinshagen 1984; Bokhoven 1987; Verbong, van Selm et al. 2001; HollandSolar 2007).

However, towards the end of the eighties the Dutch government has its doubts about PV as a suitable renewable energy technology for the Netherlands. The doubts are related to the fact whether the Netherlands are sunny enough for PV to generate substantial amounts of power and to the question on how to fit PV in a strongly centralised energy system. However, in spite of these doubts the Dutch government starts to develop instruments to create a market for PV. They

[1] In Dutch: NOZ-PV, Nationaal OnderZoeksprogramma PV

implement the 'Support Regulation Energy Savings and Flow Energy'[2] (SES) in 1988 and will renew it in 1991. This regulation states that 40% of the purchase costs of a PV system are compensated (N&M 1990; DE 1991) (F6, F5). In addition after 1990 the research strategy for PV starts to change; the attention shifts towards improving the efficiency of complete modules or the balance of system. For these reasons a substantial part of the budget (about 4.1 million euros) is reserved for system research in the second NOZ-PV (1990-1994) (DE 1992; DE 1993; Verbong, van Selm et al. 2001).

In 1990 the 'White Paper on Energy Savings'[3] is published. The goal is that in 2010 PV has to replace 2 PJ of fossil fuels, which is equal to 240 MWp of PV modules (F4). This is the first time that a specific aim is formulated for PV. This is a clear response to the high oil prices (Andriessen 1993; EnergieNed 2000; Verbong, van Selm et al. 2001). Shortly after another white paper is introduced, that lays out the Dutch policy intentions on how to deal with the environment: the 'National Environmental Policy Plan'[4] (NMP) (F4). This white paper inspires the energy distribution companies to dedicate themselves to provide a substantial contribution to a sustainable and environment friendly energy supply (EnergieNed 2000; Verbong, van Selm et al. 2001). This is written down in their first 'Environmental Action Plan'[5] (MAP-1) in 1991 (F4). In this plan measures are elaborated to achieve a CO2 emission reduction of 9 million tons by 2000, i.e. a reduction of 10% (EnergieNed 2000).

These additional policy papers by the government and the statements of the distribution companies are a strong indication for the insiders that they are on the right track. This triggers their expectations and they start to carry out more research in order to contribute to a well working 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 (F3), originating from both the research world and the industrial sector. These research groups have

[2] In Dutch: Steunregeling voor Energiebesparing en Stromingsenergie
[3] In Dutch: Nota Energiebesparing
[4] In Dutch: Nationaal Milieubeleidsplan
[5] In Dutch: Milieu Actie Plan

an important role during this phase of the PV innovation system. In 1994, ECN and the company R&S[6] produce an industrial PV module with an efficiency of 16%, and R&S starts a pilot production line for multi-crystalline silicon PV (F1). The Netherlands acquire an important position in global PV research with these technological improvements (DE 1994a; E&M 1994a). In addition some research projects are set up by several Dutch Universities (F2), where PV is placed on house roofs (e.g. Castricum, Amersfoort-Nieuwland, Heerhugowaard-City of the Sun, Barendrecht) (F1) (Schoen 2001; Verbong, van Selm et al. 2001). These projects not only lead to knowledge development on PV system performance (F2), but also guide the search by highlighting the importance of this technology (F4).

In this period we observe positive results from research (F2), which trigger insiders to lobby (F7) for better institutional conditions (F4). Once more specific budgets and aims are formulated for PV the first projects are set up by entrepreneurs (F1). Thus, here we observe a first motor of change, which according to recent research by Suurs (2009), is labelled as Entrepreneurial Motor.

The rise of the PV innovation system (1994-2001)

A turning point occurs in 1994 when the government wants to stop the SES subsidies on small-scale PV projects (-F4). 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 1995 the Third Energy White Paper[7] is introduced, and in order to achieve the goals of market formation and energy saving, several generic programmes and policies for renewable energies are set up (see Table 1 for an overview for the programmes and policies).

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[6] R&S = Renewable Energy Systems, a subsidiary company of Shell, who took over the employees of Holec Energy Systems B.V. in 1984. In 1981 Holec Energy Systems BV was founded and produced semi-crystalline silicon panels (Verbong, van Selm et al. 2001)

[7] The aim is to achieve a 10% share of renewable energies in 2020. PV comes on the third place as important renewable energy technology, but its actual impact will be for the long-term (EZ 1995)

Table 1 Overview of programmes and policies

Period	Financial stimulation	Aim
1996 – 2003	REB	To reduce the energy use of companies and households. It comprised a tax on the use of energy
1996 – 2003	VAMIL	To accelerate depreciation of investment which were included on the energy list
1996 – still running	EIA	To offset investments in technologies against taxable profit which were included on the energy list
1996 – 2004	BSE	To stimulate the use of sustainable energy and environmental energy technologies by providing subsidy for research and development projects in the field of renewable energy
1996 – still running	Green Funds	To stimulate private investments in environmentally friendly projects like PV by means of a tax exemption of this interest
1997 – 2000	EBF	To give the possibility to lean money for investments in energy saving technologies against a lower interest (3%)
1997 – 2004	EET	To come to a solution of the CO_2-problem by development and application of new and innovative technologies

However these programmes and measures are not specific for PV and SenterNovem starts to prepare the follow-up for a third national research programme on PV (NOZ-PV 96-00), which will run until the year 2000. This research programme is more market oriented than the previous two programmes. The main aim of the programme is the realisation of conditions and the removal of the bottlenecks for the large-scale implementation of PV panels in the Dutch energy system in the twenty first century (DE 1995b; Roos and Blom 2001). This ambition reflects the belief of the government that PV will only play a role in the long-term and on large-scale (F4).

In the second half of the nineties PV forms the largest expenditure post in the field of development of renewable energy in the Netherlands (F2) (Verbong, van Selm et al. 2001). The main subsidy that supports PV in a favourable way is the EPR[8], introduced in 1998, where house owners obtain about 1.59 Euro for each installed Wp (Schaeffer, Seebregts et al. 2004). This leads to the situation that entrepreneurs become more active (F1), starting the development of a Dutch PV market (F5) (EnergieVerslag 1997). In 1997, R&S becomes Shell Solar Energy BV and opens a new production line for multi-crystalline silicon PV panels 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 become active in the introduction of PV, such as NUON, PNEM and REMU (DE 1995; E&M 1998; Mierlo 2006). Large-scale roof projects are set up in this period, in for example Amsterdam, Amersfoort and the HAL project[9] (F1) (EnergieVerslag 1997; Mierlo 2006). Also NGO's start to become active and behave like real entrepreneurs: Greenpeace starts the "Solaris" project which offers customers a complete PV module for 500 Euros (F1). Together with another programme "PV GO!"[10] they install PV modules on more than 3000 houses (DE 2000; Schoen 2001). The realisation of these projects together can be seen as an attempt to create a mass market for PV in The Netherlands by lowering prices due to benefits of scale and learning experiences. At the same time the research in the Netherlands focuses on several items which are closely linked, namely cost reductions, performance improvements and integration into buildings.

In the beginning of the 21st century a large political shift takes place in the parliament. A coalition agreement is implemented where from 2003 onwards, 500 million Euros have to be saved every year on energy and environmental subsidies (PV-Nieuwsbrieven 2002/2003). The reason for this is the large amount of financial stimulations[11] for PV and a lot of free-riding, as some projects obtain financial support from several programmes simultaneously (PV-Nieuwsbrieven 2002/2003). In some regions, where the utility Eneco had taken over the utility REMU, the addition of subsidies lead to the absurd situation that PV systems could be purchased for about 0.01 Euro/Wp. Due to these exaggerated subsidies and free-riding behaviour the government decided to reduce the expenditure on PV (PV-Nieuwsbrieven 2002/2003).

In addition, on the first of July 2001, the green energy market is liberalised (DE 2001a). From this moment on PV has to compete on a free market with cheaper competing renewable energy options. It is feared that the diffusion of PV could be endangered, but contrarily to other renewable energy technologies

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8 In Dutch: Energie Premie Regeling

9 The aim of the HAL project is the realisation of an emission-free city, which uses up to 5 MW PV on the Vinex-location between Heerhugowaard, Alkmaar and Langedijk (HAL-location)

10 In 2000 NOVEM launched the PV-GO! rebate programme for small systems as well as PV on large buildings. PV-GO! contributes up to 25% of the system costs.

11 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). Most programmes were of short duration and ended

(such as biomass digestion or gasification that collapsed after the liberalisation) the installed capacity of PV continues to grow (see Figure 2). This is due to the previously implemented EPR regulation and the support from environmental organisations (Greenpeace, WWF) and energy distribution companies (Nuon and Eneco Energy), which introduce projects aimed to gain experience so that future projects could learn from it in such a manner that the diffusion of PV in the Netherlands will increase in the future. One of those projects is the, at that time, largest roof-integrated PV-system of the world on the roof of the 'Floriade'[12] (DE 2002a). In addition the market for small-scale PV systems is boosted by dedicated campaigns of municipalities, some of them offering extra subsidies. One example is 'ZonZeker' (Province of Groningen and Essent), which stimulates consumers to buy PV modules and boilers (DE 2001c). Another is the programme called 'More roofs under the sun' (Novem) in order to stimulate house building agencies to include PV (DE 2004b). Together these activities reinforce the importance of the image of solar energy in the liberalised green energy market (Sinke, Swens et al. 2008).

Concluding it can be said that this is a very successful period with respect to the formation of a PV innovation system in The Netherlands. The insiders succeed in developing the PV technology and keeping it on the political agenda. Outsiders enter the innovation system and start to set up projects, open the market and create learning experiences. The government provides the necessary conditions in which these activities can flourish. In this period we observe an expanding motor of change, called 'System Building Motor' (Suurs 2009) where functions like market formation and entrepreneurial activities add to the previous 'Entrepreneurial motor' that evolved around lobby and entrepreneurial activities. The most important result of these activities is that 10 years ago PV was no option for the Netherlands, but by now it is the most promising of all renewable energy technologies (Verbong, van Selm et al. 2001).

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also in this period due to the coalition agreement. (SenterNovem; sunergy.thrijswijk.nl; Haas 2002; DE 2003a; Sinke, Swens et al. 2008).

[12] Worlds horticulture exposition in the Netherlands

The fall of the PV innovation system (2002-2006)

This period starts with a bad omen, when in December 2002, Shell Solar announces the closing of the PV plant in Helmond (-F1); one reason being that they want to concentrate their activities in North-America, Germany and Portugal. A second reason is to streamline the production after starting a joint venture between Shell Solar Energy and Siemens (DE 2002b; DE 2004). With the closure of the plant in Helmond the production of solar panels decreases to practically zero in the Netherlands, while a new plant is built in Germany using all knowledge generated in the Netherlands (TW 1997a; DE 1997b; TW 1997b).

The interest in other countries can be explained by the growth of the worldwide PV market. The Dutch entrepreneurs notice this upcoming market and try to remain in the race as leading countries in terms of knowledge and technology production. This leads to a boost of activities by Dutch entrepreneurs concentrating on the export market such as Germany and Spain. Those latter countries enjoy favourable financial stimuli (such as high feed-in tariffs for PV), whereas the Dutch PV sector is ‘hunted’ by unfavourable and inconsistent policies, such as repeated postponement of the promised strengthening of energy performance standards, and the revoking of specific technology subsidies focused on solar energy (HollandSolar 2007). The lowest point is reached when the EPR is suddenly stopped in 2003. The announcement of the Ministry of Environment that the EPR will be stopped within one month, results in a ‘gold rush’ by actors in the PV sector in order to exploit this subsidy as long as it lasts; In that last month about 90,000 PV panels are sold to households (about 8 million kWh per year, corresponding to a consumption of 2.500 households), for a value of 100 million Euros (www.yourenergy.net). However, after this rush it is expected that thousands of jobs (installers and consultants) will be lost and knowledge about the technology and the installation will decrease (Volkskrant 2003). This will also lead to a diminishing willingness in the business sector to make investments in solar energy (-F6), dwindling involvement by companies and organisations in general (-F7), and a drop in the net sales (HollandSolar 2007). Finally, the installed capacity of PV per year in the Netherlands drops from 19.3 MW in 2003 to almost zero for the next three years (see Figure 2).

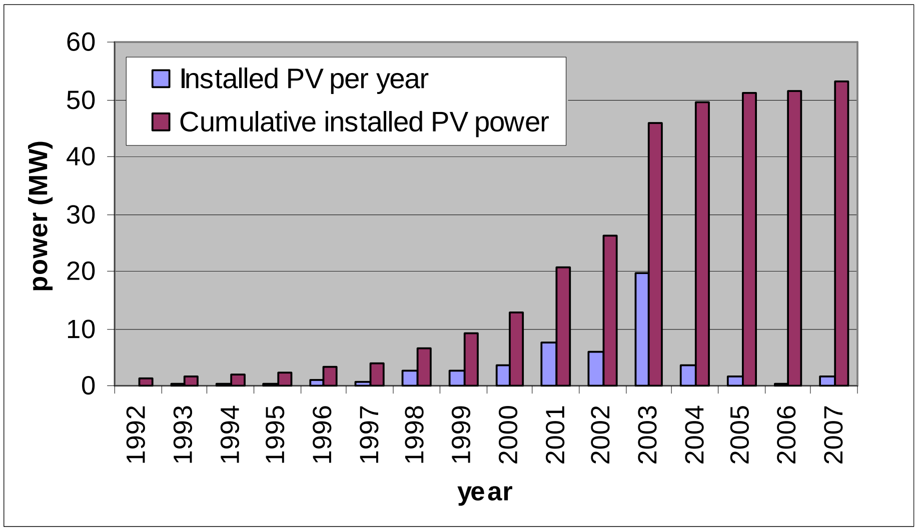

Figure 1 Installed PV in the Netherlands per year (IEA 2007)

Nonetheless, another subsidy, the MEP[13], is introduced in the same year in order to replace the EPR. The main aim of the MEP is to stimulate the production of renewable energy in the Netherlands (F5) (SenterNovem). However, the tariff for PV is limited to 6,8 Euro cents per kWh which in comparison to the EPR (12,25 Euro cents per kWh), is too low. This means that it is very unlikely that this regulation will increase the investments in PV and entrepreneurial activities, as the costs for PV modules will remain very high (Sinke, Swens et al. 2008). Therefore, a strong advocacy coalition by Holland Solar is formed amongst energy research, industry and policy professionals, in order to lobby for programmes that contribute to the future of PV technology development 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[14]. These programmes cover a full range of renewable energy technologies where PV is one of the priority areas (Heppener, Boomsma et al. 2002). In addition Holland Solar

[13] In Dutch: 'Milieukwaliteit Elektriciteitsproductie' (MEP); In English: 'Environmental Quality of Electricity Production' (IEA). The MEP is a kWh subsidy paid to domestic producers of electricity from renewable sources and CHP who feed-in to the national grid. The State guarantees the subsidy for a maximum of ten years, though not for CHP.

[14] The New Energy Research (NEO), Innovation Subsidy Collaboration Projects (IS), Energy Research Subsidy – Demonstration (EOS DEMO), Energy Research Subsidy - Long Term (EOS LT), Transition - Unique Opportunities Scheme (Transition UKR) (SenterNovem; Heppener, Boomsma et al. 2002; Sinke, Swens et al. 2008).

formulates a vision for the future of PV, which is used as a basis for the formulation of the PV transition path (Sinke, Swens et al. 2008).
During this period research institutes (such as ECN and TNO) and universities such as the Technical University of Eindhoven (TU/e), Technical University of Delft (TUD), and Utrecht University (UU), continue their research and focus 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[15] (SenterNovem; DE 2003b). For example, the European PV catapult project is being coordinated by ECN, with the aim to join forces on a European level in order to contribute to the further development of PV into a competitive technology that can be applied on large scale and to the strengthening of the position of the European PV industry on the global market. Therefore, the European Photovoltaic Industry Association (EPIA) is an important partner in formulating a Strategic Research Agenda (SRA). The SRA defines broadly supported overall development targets for PV technology and outlines research fields and topics to be addressed in order to reach these targets. In this context cost reduction of PV electricity generation and the increase of capacity is crucial (ECN-Nieuwsbrief 2004; Sinke 2007).

Beside these European support programmes there is also the Joint Solar Programme (2004) which is financed for 50% by the Foundation for Fundamental Research on Matter (FOM) and 50% by Shell. The aim of this programme is to carry out fundamental and exploratory research on PV conversion, and to increase the efficiency of PV modules (TW 2004; FOM 2008). Recently, this research programme is continued with NUON as industry partner instead of Shell (ODE 2008; FOM 2009).

Another very important event that occurs in 2003 is the set up of Solland Solar by Mr Gosse Boxhoorn. Previously he worked at Shell but started his own PV-panel factory in the Netherlands in order "to avoid valuable brain-drain" (Stromen 2004). The location for this factory is in the region of Eindhoven-Aachen-Leeuven (later on called ‘Avantis’, a European Science and Business Park), because most of the knowledge is available there and the total investments of 20 million Euros will be provided by the Province of Limburg and the Municipalities of Heerlen and Aachen (Stromen 2004; Stromen 2004). 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).

Attracted by the growth of the PV market and the favourable conditions of the Avantis Park, another solar company becomes active in the Netherlands, called ‘Scheuten Solar’, originally a glass company, which wants to produce their own crystalline-Si and set up a PV-panel factory as well. The silicon factory is constructed on the Avantis location, whereas the PV panel factory is located in Venlo, where they have their own R&D department on CIS thin-film technology (ScheutenSolar 2007).

This boost in activities shows the faith of entrepreneurs and industry in a sunny future for PV panels and system mainly as export products, and less as a renewable energy technology that could contribute to the Dutch energy supply, due to the unfavourable and inconsistent regulations. Nonetheless, Holland Solar continues the lobby activities and believes that solar energy could still contribute to the renewable energy supply of the Netherlands. In collaboration with the Dutch PV sector the ‘Roadmap Solar Energy’ is set up in 2005, where the vision on the future and also the steps for further market development are described (Bode 2005). This roadmap is offered to the government as input in order to formulate a common vision; however the government does not include it in its future agenda (Sinke, Swens et al. 2008).

Then, in 2006 another shock hits the renewable energy and PV sector, when without any notice the MEP subsidy is stopped by the Ministry of Economic Affairs. The official reason being that the goal of 10% renewable energy in 2010

[15] Crystal Clear, European PV Technology Platform, FullSpectrum, Performance, PV-catapult, PV Policy Group, PVSAT-2, and PV-TRAC (Photovoltaic Technology Research Advisory Council).

will be achieved easily without subsidies, whereas the actual reason is supposed to be the expiration of the governmental budget (Energie+ 2006). This action severely damages trust in the Dutch government by actors in the renewable energy field including the PV sector.

Summarising, this period is dominated by the unpredictability of the government. Renewable energies, and PV being no exception, are not the first priority of the government and the whole renewable energy sector suffers from it. This results in decreasing investments in the Dutch PV sector, and a shift by investors, manufacturers and entrepreneurs towards the worldwide PV market, looking for support and collaboration on European level, or financial support by neighbouring countries (for example municipalities in Germany). Nonetheless this shift the research activities within the PV sector manage to survive, since there is enough support for R&D (i.e. EOS programme). Also the production activities in the Netherlands (Solland Solar, Scheuten Solar etc) continue due to export, however the actual implementation of the PV technology in the Netherlands drops in a few years from 19.3 MW installed in 2003 to hardly anything being installed in the next three years. This results in a collapse of the Dutch PV innovation system, as the previous positive motors of change transform into a ‘motor of decline’ (Suurs 2009).

Revival of PV in the Netherlands (2007-2009)?

On 22 February 2007 the new cabinet launches a new coalition agreement[16] in order to transform the energy supply into a more sustainable and efficient one (Coalitieakkoord 2007; Bundy 2008; Sinke, Swens et al. 2008). As part of the Dutch energy transition policy a ‘Transition platform for renewable electricity supply’[17] (TP-DEV) is established in order to enable the transition towards a sustainable electricity supply. The platform is initiated with the goal to evaluate the existing policy concerning PV, to formulate recommendations for the government on desired and required legislation and to realise the above mentioned

[16] The Dutch government pledges for 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.
[17] In Dutch: ‘Transitieplatform Duurzame Elektriciteitsvoorziening’

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). This initiative of the government seems to provide some intention of commitment to seriously realise the implementation of renewable energy technologies, and triggers several activities within the Dutch PV sector.

Firstly, a research institute, FESTpv, is located on the industrial park ‘Avantis’, by the European PV industry (Solland Solar, TSM, Scheuten Solar, Econcern, Rena, Applied Materials Schwitzerland, Ersol wafers, Pillar and Vesuvius) together with ECN and the International Solar Energy Research Centre (ISC) (Germany), in order to be able to compete with the conventional energy system, thus to enable large-scale implementation. The aim is to develop cheaper solar cells by improving the material quality and production process for silicon (DeLimburger 2007; ECN 2007; Energie+ 2007).

Secondly, a third solar company starts, called Advanced Photovoltaic Applications BV (APA), established in Bleiswijk (Leeuwarden). This is a spin-off of the companies Advanced Surface Technology BV (AST), Nano Energy Europe (NEE) and SolarTotal BV. The technology of the CIS factory is based on the spray deposition technique developed by AST, which will be cheaper than the conventional techniques and materials (Si) used and is expected to lead to a breakthrough of PV technology (AD 2007; FEM.Business 2007; TW 2007).

These activities from the government and from the PV sector could form the beginning of the so-long awaited large-scale implementation of PV in the Netherlands.

Finally, in April 2008 another impulse for the investment in renewable energy will be generated with the new subsidy programme ‘Stimulation of Renewable Energy production’[18] by the Ministry of Economic Affairs (SDE) (F5). The tariffs for PV are set to 0.3 Euros/kWh (for small-scale systems between 0.6 kWp-3 kWp), however the PV sector predicts that these tariffs are still too low as the

[18] In Dutch: Subsidie Duurzame Energie

yearly costs (registration metering etc) will be just as high. On top of that, in May 2008 there are more applications than money available, i.e. about 8000 applications with a capacity of 17,8 MW, whereas the budget is only available for 10 MW (NWEA 2008; ODE 2009). The aim of this subsidy is to install a large scale PV market in 2008, however, the expectations are negative on whether this will happen (Sinke, Swens et al. 2008). On one side there is the lack of expertise and skills on how to install PV panels on the house roofs and to connect the PV systems to the electricity grid, since the Dutch PV sector has been inactive since 2003. Experts predict that it will take several years before the sector is back on track in order to realise the wished for large-scale implementation (Sinke, Swens et al. 2008). In 2008 this delay is already observed as the actual realisation of the previously applied projects for subsidy is lower than expected. This results from the complex administration procedures that are required when adopting PV panels and the lack of capable installers who can realise the complex installation procedures. This delay is also predicted to continue in 2009 as these problems and barriers are not yet solved (ODE, 2009).

Thus, in this period the motor of decline prevails resulting that it will take some time before activities will have positive impacts and start a positive motor of change.

Conclusion

Our analysis presents a dualistic view on the build up of the TIS. On one hand we see a continuously increasing knowledge base and a rise in entrepreneurial activities related to PV production. These are important indicators for a well functioning innovation system.

On the other hand we observed a strongly fluctuating market formation function. Periods where market formation stopped resulted in 'motors of decline' that deteriorated the state of the TIS. From previous studies (Negro, Hekkert et al. 2007; Negro and Hekkert 2008; Negro, Hekkert et al. 2008; Negro, Suurs et al. 2008; Suurs 2009) we observed that strongly fluctuating guidance of the search and lack of market formation proved to be very damaging for innovation system build up. Surprisingly, two very important functions (knowledge development and entrepreneurial activities) were not very much affected by the periods of poor market formation. A stable home market is normally an important factor that increases success chances of entrepreneurs. As Porter (1990) (p.70-71) has put it: a nation can only achieve international success in a particular industry if their home base (the national innovation system) "…allows and supports the most rapid accumulation of specialised assets and skills, affords better ongoing information and insight into product and process needs, and when the goals of owners, managers, and actors in the field support intense commitment and sustained investment". Furthermore, Sagar and van der Zwaan (2006) argue that R&D and 'learning-by-doing' are the main contributors (complementary to each other and interlinked) to technological change. Thus, targeted efforts are needed to promote deployment of new energy technologies by translating the results from R&D activities to 'learning-by-doing' in order to achieve changes in the trajectory of the country's energy system (Sagar and van der Zwaan 2006).

However, as the Netherlands did not pursue consistent efforts to promote deployment one could think that they left this role over to the neighbouring German market. The German market was a good enough substitute for the home market to keep the sector going also in times when Dutch policy was not in favour of creating a market for solar energy. This has implications for TIS analysis and policy. Earlier Hekkert et al (2007) claimed that a TIS crosses national boundaries, especially for system functions such as knowledge development and knowledge diffusion. However, much of the guidance and favourable institutions were claimed to be often local, which was an argument for delineating the TIS under study to the level of a nation. This example shows that also for these functions international influences need to be taken into account. Therefore, the policy implication might be that a government may decide not to strengthen some parts of the innovation system when neighbouring countries fulfil these functions sufficiently.

This of course creates two types of risks. First, this strategy might lead to the build up of a PV sector, but certainly not in reaching national sustainable energy goals. Second, only knowledge development and entrepreneurial activities related to engineering and built PV cells are kept alive. Other complementary knowledge and entrepreneurial activities are not supported, such as integration of PV in design of houses, knowledge about installation, easy net metering, services related to feed back of solar energy in the grid and so on. In short, an important part of the innovation system that is necessary to make PV an integral part of the energy system is not build up, which of course is risky. These risks are a plea for creating a home market as an integral part of the innovation system build up. This observed consistency of stimulating R&D, but much less the rest of the innovation system, is still very much in line with the 'linear model' thinking, where it is believed that innovation is a linear process of "science finds, industry applies and man conforms" (Smits and Kuhlmann 2004).

The strange twist in the story described in this paper is the renewed interest in market formation by the Dutch government in recent years. From this it becomes clear that apparently consistency in policy is not seen as a necessity for successful technology development and diffusion. This is also in line with linear model thinking. The basic argument is then: when the science base is well taken care of, diffusion will automatically take place when a market is created. However, when an innovation system perspective is the basis of policy making then the opposite reasoning is expected. In this case, a 'stop and go' policy regarding market formation only leads to a decline of entrepreneurs, guidance, legitimation, and resources. This lack of systems thinking is a major problem when we take the transition towards a sustainable energy system serious. In order to get the innovation system build up process going again after these periods of decline takes a long time. In addition, transition is only possible with high degrees of consistency regarding the creation of the right boundary conditions in which the technology in question can flourish. Policy strategies should therefore target the fulfilment of all system functions in a continuous and long-term way in order for motors of change to occur that contribute to the build up of the innovation system and the implementation of the technology in question. Specifically, system functions such as guidance of the search and market formation need to be targeted by continuous and long-term efforts.

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