Universiteit Utrecht

Relations between entrepreneurs and incumbents in the transition to wind and solar energy technology within the Netherlands:

Master-Thesis

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Summary

In this research the development of the relations between actors involved in the technological transition to wind and solar energy technology is analyzed**.** This study analyzed why and/or what factors influenced the relations between the entrepreneurial and incumbent technology producers, technology users and the government in the transition to sustainable energy technologies. The research starts with a building a narrative of the developments of wind and solar energy technology and their utilization in the Netherlands. Important historical events derived from extensive literature review and interviews with experts are used to build these narrative. Secondly, the patterns of relationships and the change of these patterns between the actors involved in the transition to wind and solar energy technology are analyzed. Finally, the patterns of relationships and the change of these patterns between the involved actors in both cases are compared with each other.

In general, the answer to the research question, *´how the relations develop between the entrepreneurs and incumbents´* is, there were no direct relations available between the entrepreneurs and incumbents. In both cases, the incumbents dominated the market in the predevelopment phase of the technology and the entrepreneurs significantly enter the market when the incumbents stopped their activities**.** The entrepreneurs step too late in a technological field abandoned by the incumbents due to unfavorable commercialization prospects. When the incumbents leave, the government starts to subsidize entrepreneurs in a not consistent way due political preferences. Therefore, the Dutch entrepreneurs start-up at a technological distance (lagging behind) with respect to foreign competitors with more advanced and better products.

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Wind energy technology

(W1)	Linda Kamp:	Assistant professor of wind energy at TUD
(W2)	Paul van der Oosterkamp:	Group leader renewable energy at ECN.
(W3)	Gijs van Kuijk:	Professor/Scientific Director Duwind at TUD.

Solar energy technology

(S1)	Ronald van Zolingen:	Professor Solar energy technology at TUE/ ex Senior Business Advisor Shell Solar.
(S2)	Jadranca Cace:	Owner Rencom/ ex product manager renewable energy at Nuon.
(S3)	Paul van der Oosterkamp:	Group leader renewable energy at ECN

Government

(G1)	Willem van der Heul:	Senior policy advisor renewable energy at Ministry of Economic affairs.

1. Introduction

The discussion on our future energy system becomes more important in our present-day society as a result of greenhouse gas (GHG) emissions, local air pollution and depleting fossil fuel reserves. The developed countries are largely dependent on fossil fuels from politically sensitive regions, like the Middle East and Russia. Berry et al. (1996) states that if the present trend of increasing fossil fuel use and depleting national resources continues, the developed countries will depend for 82% on imports of fossil fuels in 2030. GHG emissions (in particular CO_2) and local air pollution (in particular CO, VOC and NO_x) are other important issues that plead for another energy system. The Kyoto protocol, established in 1997, is a global attempt to reduce GHG emissions (Matsumura, 2001). As a result, the European Commission (EC) and the Netherlands aim to produce 20% of the total energy production in 2020 sustainable (Europe.EU).

In order to reduce GHG emission, local air pollution and depletion of fossil fuel reserves, sustainable innovations are considered as a solution. First of all sustainable innovation is a fusion of two major concepts: sustainability and innovation. The most used definition of the concept sustainability comes from the World Commission on Environment and Development in 1987 as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Dunphy et all, 2000 p.22). The concept innovation can be seen as an incremental or radical change in thinking, processes, products or organizations. The concept of sustainable innovations should thus be understood as a process of change where sustainability is considered and is defined as "*innovation leading to more sustainable technological and institutional systems and processes"* (Foxon and Pearsson, 2008 p.148).

Sustainable innovation is a complex process and a broad topic. It involves changes in socio technical systems and societal changes (Kemp et all, 2007). The transition of technologies can be seen as major transformations of technologies in societal functions. Transition processes do not only require technological changes to sustainability, but also changes in regulations, user practices, industrial networks and infrastructure (Geels, 2002). In order to analyze socio-technical transitions, Geels (2002) developed the Multi-Level Perspective (MLP). This model can be used for analyzing the possible pathways to a transition of sustainable energy technologies. Three functional levels, i.e. *niche, regime and landscape* are highlighted in this perspective (Geels, 2002). Major actors in the transition to sustainable innovations are the incumbent firms and the government at the regime level and entrepreneurs at the niche level.

The *incumbent firms* should consider their responsibility regarding sustainability. They must innovate on a large scale to provide products, processes and services that are (more) sustainable (DeSimone and Popoff, 1997). The *government* can influence the transition process via their policies. Policies can be regarded as regulations of processes and systems that lead to innovation and diffusion of sustainable technologies. Regulations by the government may stimulate and promote the development of sustainable innovations in the country, sectors or firms (Foxon and Pearsson, 2008). The government can be seen as a stimulator, facilitator, controller and director in the different phases of a transition process (Kemp and Rotmans, 2005). The final actor considered in this analysis is the *entrepreneur*. Schumpeter conceived new entrepreneurial activities as pivotal for economic development (Aghion and Howitt 1997). These activities play an important role in the development of new products and markets that promote employment, wealth for society and technical innovations for industries.

The main problem in the transition to sustainable energy technologies are the uncertainties in the diffusion and development of the technology (Anderson and Tushman, 2001). First of all, there is a technological uncertainty because the performance of new technologies is initially less than that of the existing technologies. However, not only the new technology itself is uncertain but also the socio-institutional setting wherein the sustainable energy technology will be embedded (Tushman and Rosenkopf, 1992). The role of the entrepreneur in the development and commercialization of sustainable energy technologies is to use new technologies, markets and networks to create an advantage in new business opportunities (Hekkert and Suurs et al, 2007). The entrepreneurs (suppliers of innovative technologies) face uncertainties about the demand of the market and the requirements of users, but the potential users also face uncertainty about the performance of the new technology (Tushman and Rosenkopf, 1992). At the same time, the incumbent firms dominate the existing technology, markets and the socio-technical infrastructure. Simultaneously, the government regulates the current energy structure and stimulates or blocks sustainable energy technologies. The current regulations are associated with existing technologies and do not always support the development and commercialization of new technologies (Jacobsson and Bergek, 2004). This leads to uncertainty in support mechanisms and institutional regulations for sustainable energy technologies. As a result, the involved actors in the development and commercialization of sustainable energy technologies experience limitations in different domains.

There are different kinds of sustainable energy technologies based on wind, sun and biomass as sources of energy to reduce the dependency on fossil fuels. Each of these sustainable energy technologies has its own characteristics and a different innovation system and thus a different pattern of development. In this research, the uncertainties and interactions of the actors in the wind-energy and solar-energy technology will be analyzed and compared. The wind and solar energy technology will be analyzed because both experience no successful commercialization of technological developments to the market in the Netherlands. Wind energy technology will be analyzed in this research because currently no Dutch entrepreneur is present in the transition towards this technology (Kamp, 2008). Entrepreneurs are important for the transition process because they stimulate the commercialization of new technologies and play an important role in the development of new products and markets that create employment (Van Praag and Versloot, 2007). Furthermore, the solar energy technology will be analyzed and compared with wind energy technology. This is done because the solar energy technology is in an earlier transition phase and therefore the future development path will be analyzed and compared. Now, there are many similarities between the developments in the early transition phase of the wind energy technology like many involved entrepreneurs and the development of solar energy technology. There can be thus learned from the failures of the wind energy transition. The future developments and the role there in of these entrepreneurs during the growth of applications of solar energy technology will be analyzed in order to strengthen the role of entrepreneurs in the solar energy transition.

Entrepreneurs and smaller firms are the drivers in the transition to new technologies, but they have limited resources for the development and commercialization of their products. The limited resources of entrepreneurs and smaller firms are the main problem in the transition field. This phenomenon does also occur in other sectors but this can be solved via alliance formation with incumbent firms. For example, in the biotech sector the main problem of the industry is that the entrepreneurs and smaller firms are not able to commercialize in a sufficient way their created innovative technologies (Humprey, 1996). The technological breakthrough in this industry takes place with the formation of alliances between small and large firms (Lee, 2007). Alliances are important for the discovery and development of new drugs in this industry. In the wind energy technology sector, however, all entrepreneurs have been shaken out the market. The solar energy technology industry is yet not so far developed as the wind energy technology industry. The developments in both technologies and industries will be analyzed and compared. This is also done because multiple socio-technological analyses is more robust than a single socio-technological analysis as it provides a more precise explanation of relationships and more reliable theoretical propositions (Yin, 2003).

The development of wind energy technology in the Netherlands started in 1976 with the National Research program on Wind Energy. This program provided subsidies for Research and Development (R&D) and the manufacturing of wind turbines. The goal of this research program was to develop and implement significant wind turbines in the Netherlands (Pelser, 1981). In this period, many small and large Dutch companies began to construct wind turbines with R&D subsidies obtained from the National Research program. They faced many problems like a small home market, and risky and expensive R&D projects. All manufacturers except one company were bankrupt by the year 2000 (Kamp, 2008). Currently no Dutch entrepreneurs are involved in the wind energy sector and supported by the government. Today, the large wind farms in the Netherlands are owned by incumbent firms. For example: the wind farm Eemshaven/Emmapolder with a capacity of 260 MW is owned by *Essent*, the Princes Amalia wind farm with a capacity of 120 MW is owned by *Econcern and Eneco* and the

Offshore Wind Farm Egmond aan Zee with a capacity of 108 MW is owned by *Nuon and Shell* and so on… (Wind Service Holland, 12-2009). All incumbent firms involved in the wind energy sector are supported with investment subsidies from the government. In the case of the solar energy, the technology and the implementation thereof are not that far developed as in the wind energy sector. There are now many small and large firms involved in the development and production of solar panels in the Netherlands like in wind energy technology in the year 1980. The interesting point is the destiny of these entrepreneurs in a later phase of development. This is relevant because entrepreneurs play an important role in the development of new products and markets, and technological innovations. They are expected to promote the development and diffusion of solar energy technology.

In this research, the development of the relations between the entrepreneurs and the incumbent firms in the technological transition of the wind energy sector will be analyzed. The focus in this research is not on technological developments in the transition of the wind energy technology, but on the developments of the relations between the entrepreneurs and incumbents in the transition to the wind energy technology. The entrepreneurs were involved in the first development phase of the technology and now they are not. The problems encountered and the shake out of these entrepreneurs in the wind energy sector will be analyzed. Furthermore, technology development by the actors in the solar energy technology will be investigated and compared with that of wind energy technology. The main research question of this thesis is therefore:

How did the relations between the entrepreneurs, incumbent firms, technology users and the government develop in the technological transition to wind and solar energy technology within the Netherlands?

Sub-questions:

Which problems were encountered by the entrepreneurs in the development of wind energy technology?

Why were the entrepreneurs present in the earlier phases of wind energy technology development and not in the acceleration phase?

What can be learned from the development of wind energy technology regarding the prospective development of solar energy technology?

This research wishes to find out why and/or what factors influenced the relations between the entrepreneurial and incumbent technology producers, technology users and the government in the transition to sustainable energy technologies. The research starts with a desk research. This is mainly based on an extensive literature review, which results in a conceptual model of the pattern of relationships between the actors involved. Then, interviews with experts are held to add information to the gaps in the literature. The obtained information from the desk research and interviews with experts will be used to analyze the specific patterns of relationships among the various actors involved in the transition process. The research will be finished with a discussion of the results obtained, conclusions to be drawn and the policy implications for sustainable energy transition processes.

2. Theory

In this research the development of the relations between actors involved in the technological transition to wind and solar energy technology will be analyzed. The theory section starts with socio-technological transition theory focusing on its multi-level nature. Next, the four phases of socio technological development will be described. Furthermore, the importance of resources and alliances in the transition process will be explained. Finally, the importance of interactive learning and the related relationship patterns will be highlighted.

2.1 Socio technological transition

The pattern of innovative activities takes place in various ways in technologies and industries (Malerba and Orsenigo 1997). The innovative activities regarding particular technologies are concentrated at a few innovators while regarding other technologies they take place among a lot of firms. For certain technologies the bulk of innovative activities are done by large firms, while for other technologies small firms are the main innovators. As a result, the positions of the major innovators in a sector stay stable for a long period of time or change very quickly. In general, instability of innovative activities within technologies and industries is a fundamental feature of industrial evolution (Malerba and Orsenigo, 1997). Industrial evolution is characterized by the persistence of innovative activities done by a lot of firms within an industry. The differences in technologies and industries in terms of technology entry and exit, turbulence, and high instability in the hierarchies of firms can be explained via the technological transition approach.
The concept of technological transition coincides with various patterns of innovative activities and the evolution of sustainable energy technologies over time. The concept of technological transition defines the nature of technological developments in accordance with the knowledge-based production theory (Winter, 1984; Breschi *et al.* 2000). The concept of technological transition originates from the Schumpeterian patterns of innovation. Schumpeter identified two major patterns of innovation activities: Schumpeter Mark I and Schumpeter Mark II. Schumpeter Mark I is a based on *The Theory of Economic Development* (1934). The main point of this innovative activity pattern is characterized by 'creative destruction'. It is based on the technological ease of entry and the importance of new firms and entrepreneurs in innovative activities. The second pattern of innovative activities is described as Schumpeter Mark II, and derived from *Capitalism, Socialism and Democracy* (1942). The pattern of innovative activity in Schumpeter Mark II is characterized by 'creative accumulation'. This pattern is based on the existence of large established companies and huge barriers to entry for new firms.
In order to analyze socio-technical transitions, Geels (2002) developed the Multi-Level Perspective, which integrates both visions of Schumpeter. This model will be used for analyzing the possible trajectories of a transition to a sustainable energy technology. Three functional levels *niche, regime and landscape* are highlighted in this perspective (fig.1) (Geels, 2002).

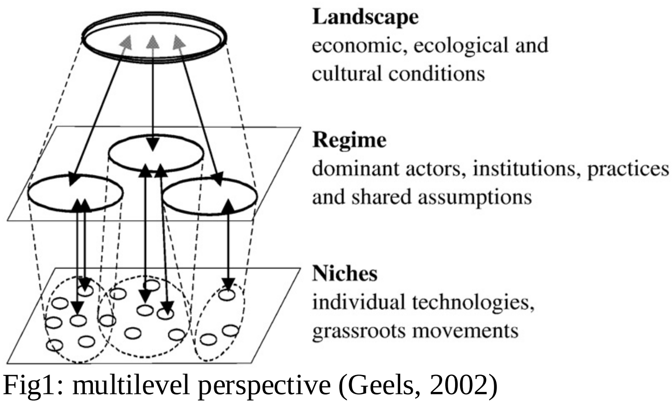

Fig1: multilevel perspective (Geels, 2002)

The MLP highlights the coordination and structuration of activities from individual technologies to large-scale social structures and institutions. The regime at the meso level can be described as the dominant culture, practices and structure (Loorbach, 2007) or the dominating practices and rules and shared assumptions (Rotmans et all, 2001). The regime level is also defined by Geels and Schot (2007) as regulations and standards, lifestyle adaptation to technical systems, investments in infrastructure machines and competences. There are seven elements that make up a regime: *infrastructure, technology, market and user practices, techno-scientific knowledge, cultural and symbolic meaning, industry and sectoral policy* (Geels, 2002). The niche level is at the micro level and can be identified in transition studies as the typical focus of radical innovation at the border or outside the (regime) meso-level. At the niche level, the development of *new technologies, markets, institutions, cultural elements are stimulated* and consist of networks of organizations and actors (Kemp et all, 1998). At the macro level, the landscape consists of deep structural trends, in which the regime is suited to fulfil its function. The landscape is an external factor or context for interactions between the actors. It can be seen as, for example *oil prices, wars, economic growth, emigrations, political conditions, environmental problems and cultural and normative values* (Geels, 2002). The landscape determines how slow or fast the development of technologies takes place (Geels and Schot 2007).
The three levels of the multi-level perspective have different types of coordination and structuration of activities in local practices (Geels, 2005). The link between the three levels can be seen as a nested hierarchy, regimes are conditioned by the landscape and the niches are conditioned by the regimes (see fig.1). The activities at the niche level are often accelerated by problems within (existing) regimes. The niche activities with their novelties hope to be implemented and used or even replace the existing regimes. This is a very difficult process, because the existing regime is institutionally, economically, organizationally and culturally embedded (Geels, 2005). Radical innovations at the niche level are often miss-matched with the current regime and do not easily break through. However, activities at the niche level are important for system innovation, because they are the sources for structural changes in the existing regimes.

2.2 Socio technological transition phases

The complex transition processes and the interplay between the dynamics at different levels in the transition of technologies are indicated above. Technological changes also can be described with the transition life cycle (Nelson and Winter 1977). This will make the complex process of socio-technological transition process better understandable. The socio-technological transition can be explained in four development phases (Van Lente, Smits et al. 2003, Rotmans, Kemp et al. 2001). These phases are the pre-development, take-off, acceleration and stabilization phase (see fig.2).

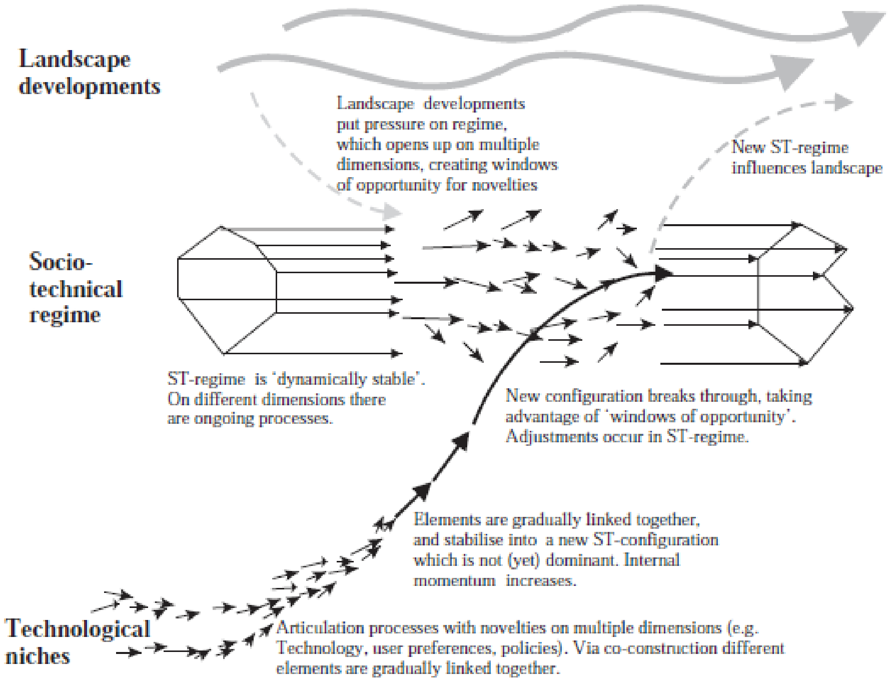

Fig. 2: Socio-technological transition curve (Geels, 2002).

The predevelopment phase is characterized by emerging novelties in niches in the context of the current regime and landscape activities. In this phase novelties emerge, together with search processes in various directions. The activities in this phase are finding out the technological possibilities and breaking the resistance to change within the current technological regime. A dominant design has not appeared yet in this phase and the different technical forms are competing with each other. The actors are experimenting to produce the best design and finding out the user's needs.

The take-off phase is characterized with the exploration of the possibilities and the expression of new futures. In this phase, the technical forms become specialized and are used in small niche markets. There emerges a community of engineers and producers directing their activities collectively towards the development of the new technology. There emerges also a new technological trajectory with its own rules and values. The interaction of the new technology and users helps to improve and explore new functionalities. The new system will be limited by the dominant system because of the occurrence of a lock-in situation and increasing returns to adoption of the currently dominant technology. Expectations about the new system also play a crucial role in the adoption of the new technology. The second phase is characterized by the emergence of a dominant design, articulation of user's needs and the stabilization of rules.

In the acceleration phase the breakthrough, diffusion and competition with the incumbent regime of the established technology take place. The breakthrough of the technology will be stimulated by internal drivers like price/performance improvements, interests of actors and increasing returns to adoption. The breakthrough also depends on external factors and opportunities. In this phase, the pressure on the regime rises through changes at the landscape level and limitations of the existing technology. This phase is also characterized by vested actors who take advantage from experiences and interactions (in other words learning by doing). Furthermore, the shakeout of technology producers takes place in this phase (Utterback 1994). There are also negative externalities in the regime, because stricter regulations and changing user needs create complications for the incumbent technology.

In the stabilization phase the old regime is replaced by the new technology. In this phase, an infrastructure and legal framework become established for the new system. It becomes entrenched in current routines with a robust system. The changes in this system are incremental and build on economies of scale. But the creation of a new socio-technological regime takes a lot of time. The incumbent firms change not so fast and focus on the old technologies because of their sunk investments and vested interests. The new regime eventually also influences wider landscape developments.

Many authors claim that technological transitions are a complex process because the existing socio-technological system hinders the development of a new socio-technological system (Kemp and Soete 1992, Freeman and Perez 1998, Jacobsson and Johnson 2000, Unruh 2002). The existing socio-technological system takes advantage of increasing returns of adoption. The advantage of increasing returns of adoption means that technologies are more attractive when they are more adopted (Arthur, 1988). This can be achieved through network externalities, learning by using, economies of scale and technological interrelatedness (Arthur, 1988). When technologies are more widely adapted, this leads to path-dependency and irreversibility of the technology. The institutions in a socio-technological system are aligned to the existing technology that leads to a lock-in of the established system (Van Lente, Smits et al. 2003). The established system increases its advantage via its history, not via its technical superiority, which makes it more difficult for the breakthrough of new technologies.

2.3 Resources and Alliances

The interesting fact is how a new technological system arises and takes over the established system. Economic development is according to Schumpeter supported by new entrepreneurial activities (Aghion and Howitt 1997). It plays an important role in the establishment of new products and markets that promote employment, wealth for society and technical innovations of industries. The factors that are related with the performance of entrepreneurs can be explained from the Resource Based View. Knowledge is a crucial part of a firm's resources (Barney, 1991). Its importance cannot easily be overlooked in today's knowledge economies, because it enables the firm to create a competitive advantage, which is difficult to imitate and socially complex. In the literature resources are seen as the strength or weakness of given firm (Wernerfelt, 1984). Resources are thus the tangible and intangible assets that are semi-permanently tied to a firm and are difficult or impossible to imitate (Teece et all, 1997). Resources are evaluated for: (1) the identification of unique resources, (2) deciding on the market with the highest returns, (3) and the decision whether the returns are most effectively utilized, for example, by integrating related markets or selling the output to related firms or business etc. (Teece et all, 1997). The resource based view highlights thus vertical integration and diversification. This perspective can be seen as capturing rents on scarce, firm specific assets whose products and services are difficult to sell in intermediate markets (Teece et all, 1997).
In order for a firm to grow, its knowledge must also continue to accumulate, especially when the environment is changing over time. Thus, knowledge can be a limitating resource. This eventually decreases other possible important resources. For example, codifying knowledge into activities and procedures makes it easier to apply experience and routines (Kogut and Zander, 1992). Knowledge is also seen as the most critical input of firm's production activities (Grant, 1996).
Learning to understand the different types of resources occurs in various ways. For example, know-what and know-why can be acquired through entering databases, reading books, and attending lectures. Other types of knowledge are embedded especially in practical experience. Know-how will commonly be learned in conditions where an apprentice follows a guide and depends on him as being the authority. Know-who is acquired in social practice and educational environments. It develops, for example, in day-to-day interactions with customers and sub-contractors. One important rational why firms conduct basic research is to acquire access to networks, consisting of academic experts that are essential for their innovative capability (Teece et all, 1997). But know-who is embedded in knowledge in a social manner which means that it is difficult to transfer through procedural channels of information.

The available resources of firms are thus crucial to be successful in emerging markets (Tushman and Anderson 1986). The incumbents have far more resources available than the entrepreneurs in an emerging market. With such an unequal competition between small and large firms, strategic positioning of firms becomes important. Alliance formation improves the position of entrepreneurs in emerging markets in several ways. Alliances provide knowledge and financial resources that allow cost and risk sharing by entrepreneurs (Miner et al. 1990, Ohmae 1989). Obtaining there extra resources by firms is helpful because emerging markets take a long time to be developed with not clear winning paths (Porter, 1980). In other words, alliances help entrepreneurs with limited resources to survive and legitimate the new product in a market, because alliances make it possible to use other firms' resources. Cooperation with different vested actors improves the speed of the formation of an emerging market (Eisenhardt and Schoonhoven, 1996).

2.4 Interactive learning and relationship patterns

An important aspect in the transition to sustainable energy technologies is interactive learning. This is the transfer of knowledge between the actors involved in the transition process. Lundvall (1992) stresses the importance of interactive learning between the technology producers and technology users. The success of a transition largely depends on the contacts between producers and users of a technology (Andersen and Lundvall, 1988). This is because, in complex transition processes, it is very difficult for small and large firms to develop all the required knowledge and skills internally. Interaction between the actors is thus required when the knowledge is tacit and difficult to formalize. And with a more complex technology the need for expertise of others increases (Lundvall, 1988). The relations between the actors involved are thus very important in the transition of sustainable energy technologies. There are three major actors identified in the pattern of relationships: technology producers, technology users and the government. The technology producers are divided in two sub actors, the fossil fuel energy technology producers and sustainable energy technology producers. These actors can be seen as incumbents and entrepreneurs that focus on the development of their technology. The second major actor consists of the technology users. The technology users are electricity producers and electricity consumers. The possible relations between these actors are shown in the conceptual modal (fig. 3). The conceptual model in figure 3 will be used to analyze the pattern of relationships and the change of these patterns between the actors involved in the transition to wind and solar energy technology.

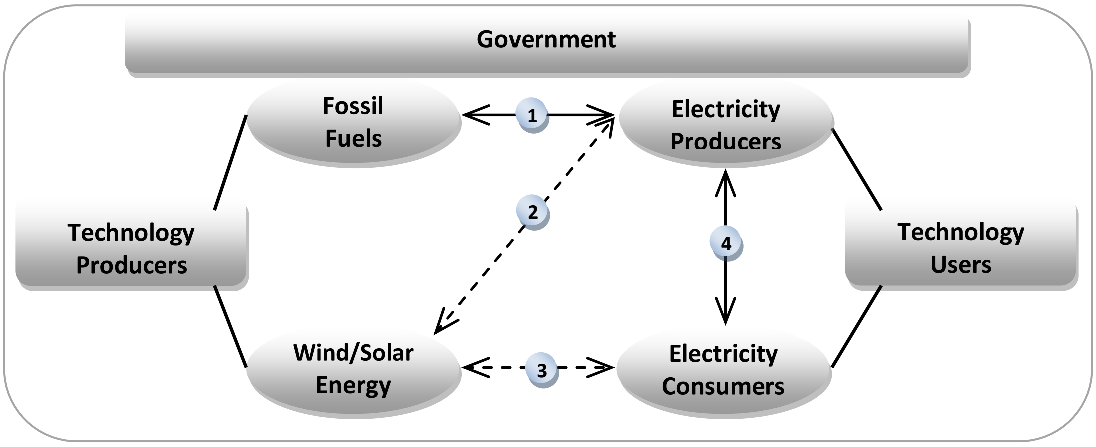

Fig. 3: Ideal patterns of relationships, Wind and Solar energy technology

In the conventional system, the relations are between the fossil fuel energy technology producers and electricity producers **(1)** and the electricity producers and electricity consumers **(4)**. In the conventional system there are no direct relations present between fossil fuel energy technology producers and the electricity consumers. In the sustainable energy system, the first possible relation is between the sustainable energy technology producers and electricity producers **(2)**. The second possible relation is between the electricity producers and consumers **(4)**. In this system, there are also relations possible between the sustainable energy technology producers and electricity consumers **(3)**. There are thus two possible pathways for the consumers to get sustainable energy, from the electricity producers or the sustainable energy technology producers. The consumers are thus able to get sustainable energy technology directly from the entrepreneurs like wind turbines or PV panels. The final considered major actor is the government; they can influence the entire relation pattern in the transition process via their policies.

The governmental regulations in the wind and solar energy sector may change over time and therefore the strengths of the relations also changes. In the predevelopment and take-off phase, the relations 2 and 3 will be weak. This is because of technological uncertainty; the performance of new technologies is initially less than that of the existing technologies (Anderson and Tushman, 2001). However, the new technology itself is not only uncertain, but also the socio-institutional setting wherein the sustainable energy technology will be embedded (Tushman and Rosenkopf, 1992). In the acceleration phase '*If the governmental regulations support the development of wind and solar energy technology, then the relations 2 and/or 3 will be strengthen*'. The development and commercialization of the technology will then grow. The sustainable energy technology producers and technology users **(2) (3)** will then become more involved. 'If *the governmental regulations obstruct the developments of the wind and solar energy technology, then the relations 2 and/or 3 will be weaken or disappear* '. The development and commercialization of sustainable energy technologies will largely depend on the stimulation programs of the government. If these programs do not support technological development or commercialization then the sustainable energy technology will not be adopted or diffuse. This means that the relation between the sustainable energy technology producers and technology users **(2) (3)** will weaken or even vanish. In this respect, policies can be regarded as regulations of processes and systems that lead to innovation and diffusion of sustainable technologies. Regulations by the government can stimulate or block some relations between different actors. In this respect, the government can be seen as a stimulator, facilitator, controller and director in the different phases of a transition process (Kemp and Rotmans, 2005).

3. Methodology

The central aim of this master-thesis is to acquire a better understanding of the relations between the entrepreneurs and incumbents during the development of wind and solar energy technology. This research also highlights the shake-out of entrepreneurs in the acceleration phase in the transition to sustainable energy technologies. This is an exploratory research, because there is still relatively little known about the strength of the relations between the actors involved in the transition to wind and solar energy technology. The research wishes to find out why and/or what factors influence the relations between the incumbents and entrepreneurs in the transition to sustainable energy technologies. The empirical research starts with a desk research. That is mainly based on extensive literature review like: newspaper articles, policy documents, technological reports and scientific journals. The desk research will be done in order to provide an overview of observed socio-technological developments of the wind and solar energy technology. The literature review forms an initial empirical outline of the pattern of relationships between the actors involved. The obtained information from literature review is not enough to evaluate the conceptual model. It is important to use various sources of information to achieve validity in a research (Yin, 1989). Therefore, interviews with experts are used to validate the obtained information from the literature review and to add information to the gaps in the literature. The advantages of open interviews are that crucial in-depth information can be collected on insights and strategies of the different actors. The disadvantage of interviews is that biased or selective answers can be given. In order to improve the reliability of this research, data from the interviews will be combined and compared with data obtained from the literature. The obtained information from the desk research and the interviews with experts will be used to analyze the specific relations between the various actors involved in the transition process. Specific information about the desk research and interviews are explained in the text below. The research will be finished with conclusions and policy implications for sustainable energy transition processes.

A case study design is chosen in order to achieve the research goals. This is done because the advantage of a case study design is that it is suitable for analyzing interactions, relations and actions of different actors in a socio-technological system (Swanborn 2000). This research addresses two cases; solar energy technology and wind energy technology. A distinction can be made between single case and multiple case designs. The reason for choosing a multiple case design is that a multiple case design is a more robust design than a single case design. It provides a more precise explanation of relationships and more reliable theoretical propositions (Yin 2003; Eisenhardt and Graebner, 2007). The focus in both case studies is on the development of sustainable energy technologies. The research is limited to developments in the Netherlands, because using the same institutional setting makes it possible to compare both cases.

In order to gain a better understanding of the role of different actors in the transition to sustainable energy technologies, the research is divided in two major parts. The first part provides an overview of the socio-technological developments, thus on *'What happened in the wind and solar energy sector?'* The second part provides a detailed analysis of the identified events and developments, thus on *'Why it happened in the wind and solar energy sector?*'. First, both case studies will be individually analyzed (within-case analyses). The data on the cases will be structured and analyzed in accordance with the theoretical framework. The developments in the technological transition of wind and solar energy technology will be described. The second part in this research aims to analyze changes in the relational patterns between the entrepreneurs and incumbents in the transition towards the implementation of wind and solar energy technology. The outcome of the first part forms the basis of a detailed explanation of the patterns derived in the second part. The findings in this part will be compared with the literature. After that, a cross-case analysis will be performed in order to identify differences in the patterns of relationships between the wind and solar energy technology.

3.1 Socio-technological developments

The first part consists of providing an overview of the socio-technological developments of the wind and solar energy technology. In this part the socio-technological developments of the cases will be investigated. This includes the following elements:

- Description of technological features.
- Description of developments taking place.
- Identification of the involved actors.
- Identification of important historical events and their effects on the pattern of relationships among the actors.

The research starts with a description of the technological features of wind and solar energy technology. The focus will be on main technological characteristics like the different types, applications, capacity and technological developments. This section will be ended with a description of how electricity can be produced with wind and solar energy technology. The second part in this section is a description of historic developments. This will be done by providing a chronological overview of the development of R&D, product development and the actions of the involved actors like incumbents, entrepreneurs, electricity production companies, electricity users and the government. The third part consists of the identification of the involved actors. The activities of the actors and their effects on R&D and market introduction will be explained. The final part of this section presents the identification of the important historical events and the changes in the patterns of relationships between the involved actors. This first major part will be ended with conclusions drawn from first research. The goal of this part is to explore the major developments and the actors involved in wind and solar energy technology. Successful and unsuccessful periods will be identified in order to focus on what and why happened during the transition process in the second part of this study. The data collection in this part consists of an extensive literature review. The literature review is based on data collection from newspaper articles, policy documents, technological reports and scientific journals. These materials are used to obtain an overview of the development of wind and solar energy technology in the Netherlands.

3.2 Specific patterns of relationships

In the second part, the first part will be used to analyze the specific relations between the various actors involved in the transition process. The data in this phase will be obtained from open interviews with key actors involved in both cases. These key actors are:

- *Professors at technical universities*: Technical universities are involved in wind and solar energy technology from beginning of the developments. They have a lot of experience with technology production, technology use and the effects of governmental regulations.

- *Technology producers*: The technology producers have a lot of experience with the development of their products. They can offer more insights in to the technological limitations and the effect of governmental policies on their market strategy.

- *Technology users*: The electricity production companies are considered as the most important user of the technology. They have a lot of experience in the use of the technology and the effect of governmental regulations

- *Government*: Policy advisors at the ministry of Economic Affairs can offer more detailed explanation of the governmental regulations and how/why the supporting programs are changed.

Various experts are interviewed because the crucial in-depth information can be collected on insights and strategies. The key actors are: manufacturers, electricity producers, electricity consumers, universities, research institutes and governmental agencies. The following interview questions will be asked to key actors in the wind and solar energy technology:

- ✓ *What were the main problems in the transition of solar/wind energy technology*
- ✓ *To what extent played technological development a role in promoting the use and production of solar/wind energy?*
- ✓ *What was the impact of the market introduction of foreign companies on promoting the use and production of solar/wind energy?*
- ✓ *What was the impact of incumbents on smaller producers in the development of the solar/wind energy technology?*
- ✓ *To what extent played the electricity producers a role in promoting the use and production of solar/wind energy?*
- ✓ *How is the collaboration between universities/research institutes and industry in the development of the solar/wind energy technology?*
- ✓ *What was the impact of government policy changes and many programs on promoting the use and production of solar/wind energy? Why did the policy changes occur?*
- ✓ *What do you think of the current developments in the solar/wind energy technology*
- ✓ *What would be the ideal solution or program to increase again the use and production of solar/wind energy in the Netherlands?*

The data from the extensive literature review and interviews with experts will be used for the analysis in this research. First, the data analysis is building a narrative of the developments of wind and solar energy technology and their utilization in the Netherlands. Important historical events derived from extensive literature review and interviews with experts will be used to build these narrative. Secondly, the narratives will be used to analyze the pattern of relationships and the change of these patterns between the actors involved in the transition to wind and solar energy technology. Finally, the patterns of relationships and the change of these patterns between the involved actors in both cases will be compared with each other.

In the next section, the research starts with building a narrative about the socio-technological developments of wind and solar energy technology. Then, the patterns of relationship between the involved actors will be analyzed and compared. Finally, the research ends with the discussion, conclusion and policy implications.

4. Socio-technological developments

4.1. Case: Wind energy technology

In the wind energy technology case, the technological features, the development of wind energy technology, the involved actors and important historical events and the relationships between the actors involved will be analyzed.

4.1.1 Technological features

Wind energy technology converts the energy of wind into electrical energy via a wind turbine. There are two most used technical types of wind turbines available; the horizontal axis wind turbine (HAT) for large scale applications and the vertical axis wind turbine (VAT) for small scale applications (see figure 4). On a HAT the blades are perpendicular to the rotating axis and on a VAT the blades are parallel to the rotating axis (Nysereda, 2005). Another difference between the two types is that the generator is situated on the top of a HAT and near the ground on a VAT. The conversion of wind energy into electrical energy will be done with a rotor that consists of slender blades connected to a hub, which converts the motion of the wind into usable mechanical motion. The rotor turns by the air flow over the blades. The motion of the rotor will be transmitted from the hub via a shaft to the generator. The generator in the wind turbine converts the rotary motion into electricity. In the generator, electricity is generated from the rotating magnetic field that is connected via a cable to the electricity grid or another load. The generator needs to rotate very rapidly in order to generate electricity at the appropriate grid frequency. A gearbox is used to increase the rotation speed in the generator because of the slowly rotating rotor (Nysereda, 2005).

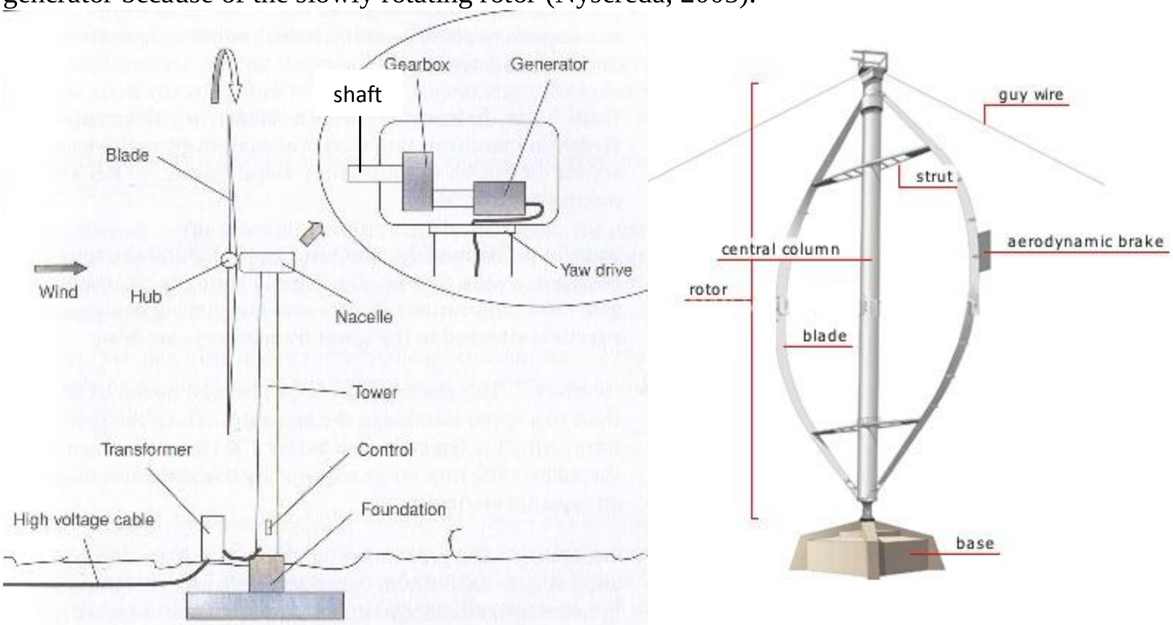

Fig. 4: ***left;*** **Horizontal axis wind turbine,** ***right;*** **Vertical axis wind turbine**

Wind generation equipment is categorized into two general classes, utility scale and residential scale. The utility scale corresponds with large wind turbines (HAT) with a capacity between 300 kW to 3 MW turbines (Enernex, 2003). This type is used to generate bulk energy for sale on the electricity market. They are commonly installed in large groups or 'wind energy parks', but can also be installed in small quantities. The other class of residential scale corresponds with small-scale turbines (VAT) with a capacity between 300 watts to 50 kW (Enernex, 2003). This type is used to generate electricity for small applications and households. This type can also be used in combination with solar energy, batteries and inverters to provide constant power. The installation of a VAT wind energy park is not possible due to the high cost making it is only suitable for remote locations.

Research and development of wind turbines led in the past ten years to an increase of the capacities of wind turbines. This is done to improve the energy capture and reduce the energy costs with technological improvements and improved design tools. For comparison, the average capacity of a wind turbine in the U.S. in 2001 was 908 kW, while the average capacity of a wind turbine in 2003 was 1.3 MW (Nysereda, 2005). The average capacity increased further in 2005 to 1,5 and 1,8 MW today (Nysereda, 2005). The technological improvements of the wind turbines led also to an increase of rotor diameters and the hub height of the wind turbines. There is no standard hub height or rotor diameter, the wind turbines become bigger and bigger to generate more electricity. An overview of the technical characteristics of different wind turbines are shown in table below

Table 1: HAT characteristics

Dimension	330 kW	850 kW	1,65 MW	2,0 MW	3,0 MW
Hub Height	37/50 m	44/74 m	80 m	60/100 m	84/119 m
Rotor Diameter	33,4 m	52 m	82 m	80 m	112 m
Max. Height	53,7/66,7 m	70/100 m	121 m	100/120 m	140/175 m

Table 2: VAT characteristics

Dimension	300 watt	1,0 kW	2,5 kW	50 kW
Rotor Diameter	1,0 m	1,9 m	1,21 m	12 m
Blade Height	1,0 m	1,9 m	3,3 m	12,5 m

4.1.2 Developments of wind-energy technology

Research on wind energy technology in the Netherlands started in 1976 with the Dutch national research program on wind energy (NOW). In this research project, subsidies were provided for research and development of wind turbines. The goal of this research project was to increase the number of wind turbines and their capacity in the Netherlands (Pelser, 1981). In this research program, two systems were developed, the large scale wind turbine system and the small scale wind turbine system.

4.1.2.1 Large scale system

In the large scale wind turbine system many research projects were done at Delft and Eindhoven Technical Universities and at the Energy Research Centre Netherlands (ECN) in order to acquire theoretical knowledge about wind turbines. This knowledge was based on the structural dynamics and aerodynamics of wind turbines. The research resulted in the early 1980s into tipvanes. Theoretical research had shown that small vanes on tips of wind turbines blades produced a higher energy yield (Van Holten, 1978). Disappointingly, the tipvanes did not succeed in practice; the large-sale system was primarily based on learning by searching. Furthermore, the knowledge gained from these research projects was applied to build three prototypes and two commercial wind turbines. There were two HATs and one VAT built to compare the energy yields and efficiencies of these wind turbines (Pelser, 1981). The first VAT prototype was built in the year 1975-1976 by the airplane manufacturing company Fokker, the machine manufacturing company Stork and the ECN research institute. (Pelser, 1981). The VAT was built to gain operational experience in wind turbine building. This VAT prototype was not successful. There were many vibrations in the blades and they produced a lot of noise (Dragt, 2000). This VAT prototype was the first and last small scale wind turbine. The airplane manufacturing company Fokker decided in 1985 to focus on its core business and no more on wind energy. In the meantime, there was also a HAT prototype built in 1981. This turbine was built by

Stork, Fokker, Holec and Rademaker at the site of the ECN research institute. The wind turbine had a capacity of 300 kW and was built to obtain operational experience (Sens, 1981). The results of this turbine were satisfactory and Stork decided to build commercial turbines. The interaction between the manufacturing companies and research institutes was very well and had the same goal (Kamp, 2002). This made interactive learning possible. However, the electricity production companies as turbine buyers were not interested in the produced wind turbine; only some local electricity production companies bought in total three wind turbines but these turbines were not found satisfactory and had many operational problems (Verbruggen, 2000). Because of these problems, Stork built a new 1 MW HAT in the year 1983. This turbine should be the step towards a 3 MW turbine, which was calculated as the most efficient turbine (Hensing and Overbeek, 1985). There is only one turbine sold with a lot of operational problems (Verbruggen, 2000). The Ministry of Economic Affairs developed also a wind power station at Sexbieruma at the end of 1983. The turbines installed there were produced by Holec but because of many design and building problems, the entire project was delayed considerably (Hutting, 2000).

At the end of the year 1989, there were many problems with designing and building wind turbines, large financial risks and a small home market. This led to the end of the production of wind turbines by Stork, Fokker and Holec. The most important cause of the problems was the shortage of learning by using. There were only a few wind turbines developed that led to limited learning by using and learning by interacting. The obtained knowledge was mostly gained via learning by searching in the large scale system.

4.1.2.2 Small scale system

In the small-scale wind turbine system, ten small companies in the Netherland started to develop and manufacture wind turbines in the period 1976-1980 (Kamp et all, 2004). The NOW program made R&D subsidies for wind energy and turbines available for these firms. The small companies had different manufacturing experiences like making polyester yachts, steel constructions and farming equipments (Stam, 2000). The main difference between the small scale wind turbine system and the large scale wing turbine system was that the knowledge base was obtained from learning by doing instead of learning by searching. The turbines were built by the way of trial and error that led to improvements and up-scaling. This process allowed directly solving the problems observed by users. The interaction with the users made it possible for the manufacturers to learn from the problems (Boersma, 2000). The research centre ECN helped the manufacturers also to improve their turbines (Stam et all, 1983). The ECN was, however, not allowed to give specific indications of the improvements because of the danger of distortion of competition (Stam, 2000). The different turbine manufacturers also did not help each other by sharing information among one another because they considered each other as competitors (Stam, 2000). Another major problem encountered by these manufacturers was the small size of the domestic home market. The Dutch home market was small because there were no subsidies available for wind turbines buyers. This resulted in long payback times (Werkgroep Duurzaam-energieplan, 1984). The delivery conditions to the electricity grid were also not good due to low buyback tariffs and limited delivery (Blok, 2000). The technical characteristics of the wind turbines improved gradually and the turbines became better and bigger. This process went however more rapidly in Denmark. During the mid 1980s, the small home market led to financial problems for the Dutch manufacturers. At that time, governmental energy policy started to get involved in the activities of the small-scale turbine manufacturers because large-scale wind turbine builders stopped their activities. The small turbine builders were seen as the producers of efficient wind turbines that could contribute to the Dutch electricity supply. The R&D subsidies for research institutes and universities were only available if the research results were applicable for small turbine manufacturers (NEOM, 1986). The Dutch government introduced also investments subsidies, which increased the home market. From then on, the small wind turbine builders cooperated with research institutes to improve their design and manufacturing process. The large-scale wind turbine builder Stork and the research institutes worked together with the small wind turbine builders to improve and scale up their wind turbines. This cooperation was difficult, because the researchers were science oriented thinkers whereas the small turbine manufacturers were builders (Boersma, 2000). This led to less development of the wind turbines and limited learning by interacting. One wind turbine manufacturer, Lagerwey, had a different approach. They did not accept direct interventions of researchers in their developments but applied useful ideas from personal contacts in Delft. This led to improvements in their small wind turbines, with components developed at Technical University Delft (Van Holten, 2000). The problems with the advanced components of wind turbines, combined with the small home market and the competition of Danish firms with better products resulted in the bankruptcy of many Dutch manufacturers in the 1990s. Today, only one Dutch turbine manufacturer, Lagerwey, is still alive.

4.1.3 Involved actors

Since 1975, large firms, entrepreneurs, electricity production companies, electricity consumers, universities and research institutes are involved in the large-scale wind turbine system. Eight firms are involved in the research and development of wind turbines: the important large firms were Fokker, Stork and Holec. The involved research institutes are KNMI, TNO, NLR, KEMA and ECN (see table 3). Furthermore, Dutch universities became involved like Delft Technical University and Groningen University (W3). The electricity production companies were considered by the government as buyers of the wind turbines but many electricity producers were not interested in wind turbines. Only a few local electricity production companies like PZEM in the Province of Zeeland, the electricity company of Schiedam in South Holland and the Kodela electricity production company in Curacao bought large-scale wind turbines (see table 4) (Kamp, 2002). There were no electricity consumers directly involved in the large scale wind turbine system.

Table 3: Government and Research institutes wind energy technology

Actors	Characteristics
Government	
LSEO	Landelijke Stuurgroep Energie Onderzoek): allocating R&D funds
NEOM	NEOM (Nederlandse Energie Ontwikkelings Maatschappij): promoting energy projects and transferring knowledge between actors
AER	Algemene Energie Raad: advise the government on energy matters
BEOP	Bureau Energie Onderzoeks Projecten: the main energy research institutes
Research institutes	
KNMI	Dutch meteorological institute
TNO	Netherlands Organization for Applied Scientific Research
NLR	National aerospace laboratory
KEMA	Research institute of the electricity sector
RCN	Reactor Centre of the Netherlands (Leader of the project)
Universities	
Eindhoven Technical University	Bibliography wind energy technology
Groningen University	Research small vertical axis turbines
Delft Technical University	Research on tipvanes

Table 4: Large-scale actors wind energy technology

Actors	Characteristics
Manufactures	
Fokker	Electrical installations for machines, *manufacturing wind turbines*
Stork	Airplane building, *manufacturing wind turbines*
Holec	Machine building, *manufacturing wind turbines*
Electricity Production Companies	Many electricity production companies were sceptic about role of wind energy in the Dutch energy provision
PZEM	Purchased 1 wind turbine

Schiedam EC	Purchased 1 wind turbine
Kodela	Purchased 1 wind turbine
Electricity Consumers	Not involved in the wind turbine innovation system

In the large-scale wind turbine system, the three wind turbine manufacturers Fokker, Stork and Holec stopped in the early 1990s with manufacturing wind turbines (Kamp, 2002). This happened because of the many technical and financial problems experienced by the firms. Stork continued with building blades and research on wind turbines.

Since 1975, the small scale wind turbine system started with small companies with no more than 10 employees manufacturing small wind turbines. These companies had different skills and manufacturing histories (see table 5). Some examples are: Van der Pol, Bohes (Bohemen Energy Systems), Bouma, Lagerwey, Nedwind, Windmaster, NHC and HMZ (Stam, 2000). The small-scale wind turbines were first only purchased by farmers living in the neighbourhood and small energy intensive companies (Wind Service Holland, 2000). The number of wind turbine buyers increased after 1985 because of the introduction of investment subsidies for wind turbines. These buyers were private and institutional investors and electricity production companies like the electricity company of Overijssel (IJsselmij) and the electricity company of North Holland (PEN)

Table 5: Small-scale actors wind energy technology

Actors	Characteristics
Manufactures	
Van der Pol	steel construction company; making wind turbines
Bohes	hydraulic transmissions; making wind turbines
Bouma	glass fibre reinforced polyester yachts; making wind turbines
NCH	farming equipment; making wind turbines
HMZ	construction company; making wind turbines
Lagerwey	making wind turbines
Nedwind	making wind turbines
Windmaster	making wind turbines
Electricity Production Companies	
Ijsselmij	Project Urk; 25 wind turbines
PEN	Project Zijpe; 15 wind turbines,
PEN	Project Callantsoog; 18 wind turbines
Electricity Consumers	
Farmers	
Small energy intensive companies	
Private and institutional investors	

In the small-scale wind turbine system, the number of manufacturers decreased during 1986-1991 from twelve to three, the manufacturers Lagerwey, Windmaster and Nedwind continued their work (Kamp 2002, W3). In the year 2000, only Lagerwey was still active in the market and is in 2010 the only wind turbine manufacturer in the Netherlands.

On the policy side, the Ministry of Economic Affairs was the major actor. The Directorate General of Energy played a guiding and coordinating role in the development of wind energy technology. The government established also four intermediary councils; LSEO, NEOM, AER and BEOP (see table 3). The focus of these governmental agencies was on R&D of wind turbines. Their program had the following goals (BEOP, 1981c)

- Supporting R&D in wind energy and turbines.
- Supporting companies that produced wind turbines.
- Advising governmental organizations to introduce wind energy into the Dutch energy provision systems.

The main goal of the government was the introduction of reliable wind turbines within three to five years. These wind turbines should contribute on a large scale to the Dutch energy provision in the year 2000. Then, there should be at least 1.000 large wind turbines with a total capacity of 2.000 MW and 15.000 small wind turbines with a total capacity of 450 MW installed in the Netherlands (BEOP, 1981c). The government didn't realize this goal in the year 2000.

4.1.4 Important historical events

The important historical events in the development of wind energy technology are chronological shown in table 6. First of all, the large-scale system started in 1975 and stopped in the year1990 with the end of the activities of Fokker, Stork and Holec. The large-scale system developed not well and entered not sufficiently on the market (W3). Therefore the focus will be on the small-scale system. The activities in the small-scale system developed as expected in the transition literature. There were many entrepreneurs involved at the beginning phase. After a shake-out, three entrepreneurs (Lagerwey, Windmaster and Nedwind) were left that also entered the market (W3). A niche market had developed; in the beginning phase with farmers and small energy intensive companies as customers and later mainly with electricity production companies and project developers as customers. The Dutch home market grew significantly when the investment subsidies for wind turbines where introduced.

Table 6: Chronological historical events wind energy technology

Events	Government	Manufacturers	Elec. production	Elec. consumers
1976-1980	**Goal**: - First oil crisis: become independent of energy imports - 1st NOW: Increase theoretical knowledge 2nd white paper energy: introduction of 2000/3000 wind turbines in the future **Actions:** - Research institutes involved - 1st NOW program - 2nd white paper on energy nota -R&D subsidies large and small-scale manufacturers	**Large-scale** -Fokker -Stork -Holec Mostly R&D **Small-scale** About 24 companies with different manufacturing histories started with manufacturing wind turbines	**Large-scale** Not involved **Small-scale** Not involved	**Large scale** Not involved **Small-scale** Nearby farmers
1981-1985	**Goal**: -2nd NOW: supporting R&D , supporting wind turbine manufacturing companies - 15.000 small wind turbines (450 MW) and 1000 large wind turbines (2000 MW) in the year 2000 **Actions:** - Research institutes involved - 2nd NOW program -Large R&D subsidies after approval by the Ministry	**Large-scale** Fokker Stork Holec R&D and manufacturing wind turbines **Small-scale** About 10 companies 6,5 MW turbine capacity installed	**Large- scale** PZEM Schiedam EC Kodela Each company bought 1 wind turbine **Small-scale** Not involved	**Large scale** Not involved **Small-scale** - Nearby farmers - Small energy intensive companies - Energy enthusiast
1986-1991	**Goal:** IPW: Integral program on wind energy	**Large-scale** -Fokker	**Large- scale** -PZEM	**Large scale** Not involved

	-Supporting the industry -1000 MW wind turbine capacity in the year 2000 **Actions:** - Start up IPW program - Subsidies for applicable research - Investment subsidies for turbine buyers dependent on the generator capacity of the wind turbine	-Stork -Holec Stopped with manufacturing wind turbines **Small-scale** 3 companies left -Lagerwey -Windmaster -Nedwind 92 MW turbine capacity installed	-Schiedam EC -Kodela Actively involved and many contracts with turbine manufacturers **Small-scale** 80% - Electricity production companies - Institutional investors Set up of wind parks - Ijsselmij: Project Urk; 25 wind turbines (7,5 MW) - PEN: Project Zijpe; 15 wind turbines (1,1MW), Project Callantsoog; 18 wind turbines (2,9 MW)	 **Small-scale** 20% - Nearby farmers - Small energy intensive companies - Energy enthusiast
1992-2010	**Goal**: -TWIN program (Application of Wind Energy in the Netherlands): - 400 MW wind turbine capacity in 1995, 1,000 MW in 2000 and 2,000 MW in 2010; -Improvements existing turbines and development larger turbines - 200 MW offshore wind turbine capacity in 2010 -MEP program (2005-2006) -SDE program (2008-) **Actions:** - Start-up IPW program - R&D subsidies - Investment subsidies until 1996	**Large-scale** Not involved **Small-Scale** 1 company left -Lagerwey Stopped with manufacturing wind turbines -Windmaster -Nedwind	**Large-scale** Not involved **Small-Scale** -Electricity production companies -Project developers	**Large-Scale** Not involved **Small-scale** - Nearby farmers - Small energy intensive companies Decreased because siting problems

The government developed also a lot of policies and programs to stimulate wind energy technology. The following wind energy programs were introduced (Kamp, 2002): 1st NOW program (1975-1980), 2nd NOW program (1981-1985), IPW program (1986-1990), TWIN program (1991-2000), MEP program (2005-2006) and from 2008 the SDE program.

The first NOW program was executed by the government during the years 1975-1980 in order to become independent of energy imports after the first oil crisis in 1973 (W3, BEOPb). The goal of this program was to gain mainly theoretical knowledge about wind energy technology. In this program different research institutes were set up and research subsidies came available. The first NOW program led to the manufacturing of small and scale large wind turbines by 24 entrepreneurs and 3 incumbent firms (Kamp, 2002). These firms began to develop and increase their knowledge about wind turbines. In this period the small scale wind turbines developed by the entrepreneurs were sold to nearby farmers.

The second NOW program was active between the years 1981-1985. This program was set-up to increase the knowledge and implementation of wind turbines manufactured in the Netherlands. The main goal of this program was the installation of 15.000 small wind turbines with a total capacity of 450 MW and 1.000 large wind turbines with a total capacity of 2000 MW in the year 2000 (BEOPc, Kamp 2002). There were research and development subsidies available for the Dutch manufacturers after approval by the ministry of Economic Affairs. The government actions led to an increase of knowledge and manufacturing skills at the small and large scale wind turbine manufacturers. The incumbents increased their manufacturing skills and sold 3 large scale wind turbines with a capacity of 300 kW, 1 MW and 3 MW to electricity production companies (W2, W3). The entrepreneurs decreased from 24 to 12 because of the necessary approval by the Ministry at research subsidies. The remaining entrepreneurs developed their small scale wind turbines further and installed wind turbines with a total capacity of 7,5 MW (BEOPc, Kamp 2002). The small scale wind turbines were also bought by nearby farmers and energy enthusiasts in this period.

After the first and second NOW programs, the government launched the IPW program between the years 1986-1991. The goal of this program was the installation of 1000 MW total wind turbine capacity in the year 2000 (NEOM, 1986). There were besides research subsidies for the manufacturers also investments subsidies for turbine buyers depending on the generator capacity per turbine bought. This was done to speed up the creation of a wind turbine market and to set pressure on turbine manufacturers to built larger wind turbines with higher capacities (W3). The IPW program led to further development of large scale wind turbines by the incumbents. The relations between the incumbents and the electricity production companies improved and they became more involved with a lot of contracts (Kamp, 2002). Despite of the further development of the large scale wind turbines, the incumbents stopped their activities at the end of this period. The many design and manufacturing problems, large financial risks and the small home market led to the end of the activities regarding the production of large scale wind turbines by the incumbents (W3, Kamp 2002). The shake-out of entrepreneurs continued in this period; at the end there were only 3 firms left. These entrepreneurs increased their knowledge and manufacturing skills through active collaboration with research institutes (W2). The total installed capacity increased to 92 MW in the year 1991 (IEA, 2000). The number of small scale turbine buyers increased enormously in this period. The electricity production companies and institutional investors became for the first time involved in small scale wind turbines. They owned 80% of the wind turbines and the remaining 20% was owned by the farmers and energy enthusiasts. There arose a small niche market for small scale wind turbines because of the introduced investments subsidies by the government. The entrepreneurs also changed their focus to building large scale wind turbines instead of improving their small scale wind turbines (W2, W3, Kamp, 2002). The shift from manufacturing small to large scale wind turbines by the entrepreneurs started at the end of this period because of pressure of the government.

The TWIN program was introduced by the government between the years 1992-2000 in order to support the further application of wind energy technology in the Netherlands. The goal of this program was the installation of 400 MW total wind turbine capacity in 1995, 1000 MW in 2000, 2000 MW in 2010 and 200 MW offshore in 2010 (Novem, 1991). Research subsidies and investment subsidies were available until 1996. The small-scale wind turbine manufacturers began to develop larger wind turbines in this period in order to meet the government goals. They developed between 1976-1991 wind turbines with a maximum capacity of 80 kW and from 1992 started to develop 250kW and then 750 kW turbines in a few years time (Kamp, 2002). The small wind turbine manufacturers changed their strategy to stay in the market and they became large scale wind turbine manufacturers. Another change in this period was the entry of foreign manufacturers into the Dutch market. The market share of the Dutch manufacturers was 98% in the year 1993 (IEA, 1998). The market share of the Dutch manufacturers decreased to 41 % in 1997 (IEA, 1998). The Dutch government focused after the 3rd white paper on energy in 1996 on foreign manufacturers with higher wind turbine capacities. This change was induced to reach the sustainable energy goals of the government in the year 2010. The cost of change and technology development became too high for the domestic entrepreneurs and the enormous competition of foreign manufacturers led to the end of

Dutch wind turbine manufacturing (W3, Boersma 2000). Lagerwey started their activities in 2006 with manufacturing also large wind turbines.

Remarkable is that the government policies regarding wind energy technology changed a lot. The Dutch government was also actively steering technology development. Business plans of wind turbine manufacturers had to be approved by the ministry to get research subsidies and owners of wind turbines had to be certified in order to receive investment subsidies. The amount of available subsidies was, however, decreased every year. The expectations of the government were too high and it was impossible for the Dutch manufacturers to meet these goals. Currently there is no national policy regarding small wind turbines. The government does not believe to reach its goals with small wind turbines; therefore they don't invest any more in small wind turbines.

4.2. Case: Solar energy technology

In the solar energy technology case, the technological features, the development of solar energy technology, the involved actors and important historical events and the relationships among the actors involved will be analyzed.

4.2.1 Technological features

Solar energy technology converts solar light into electrical energy via solar panels. The conversion of light into electrical power was discovered in 1839 and called as the photovoltaic (PV) effect (Butti and Perlin 1980). A solar panel is a packaged interconnected assembly of photovoltaic cells also known as solar cells. The photovoltaic effect is the creation of electricity with photons of light that knock electrons in a higher state of energy. The creation of electricity takes place via the generation and separation of free charge carriers. A solar cell is composed form two layers of semiconductors. These layers consist from p-type (positive) and n-type (negative), that are sandwiched together to shape a pn-junction (see figure 5).

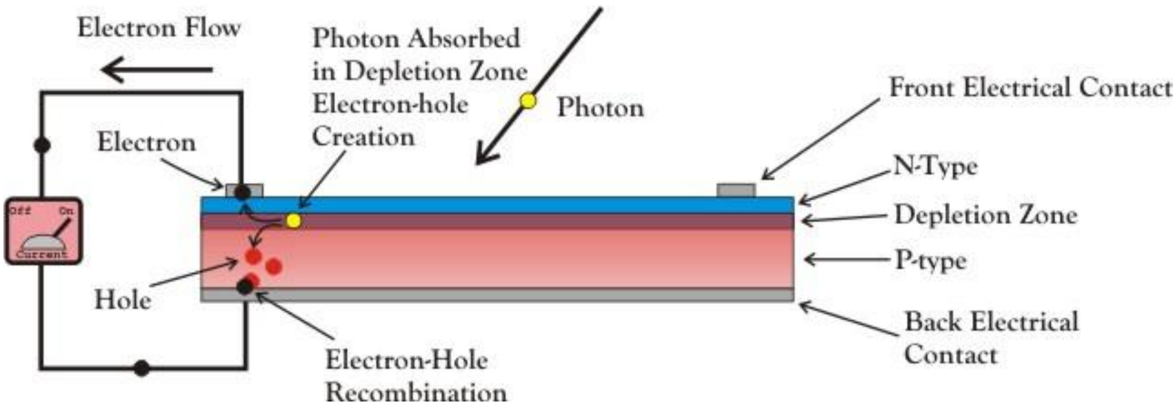

Fig. 5: Solar panel; pn-junction

The pn-junction process induces an electric field when sunlight shines across the junction. The generation of electric current takes place inside the depletion zone of the pn-junction. When light particles (photons) are absorbed by n-type silicon, it creates a free electron that jumps out the depletion zone. The free electrons will be attracted to the p-type material and travels through an external circuit and creates a flow of electric current. A dislodged electron creates also a hole that migrates to the back electrical contact. When the electron enters the p-type silicon from the external circuit it combines with the hole in the back electrical contact to restore the electrical neutrality (SETP, 2008).

There are different types of solar cell design and materials with different performances and costs. The most used first generation technology is built from crystalline silicon (c-Si) cells. This generation is quite reliable and has conversion efficiency between 15-20% (Green, 2003). Its disadvantage is the high costs due the need of large quantities of very pure silicon. The technology has been developed further during the past decades in order to reduce the costs. The improved solar cells are called the second and third generation PV technology (Green, 2005). The second generation solar cells are composites from thin-film technology. There are various types of thin-films like; amorphous silicon, cadmium telluride and dye-sensitized solar cells (Negro et all, 2009). The second generation PV technology is aiming to reach low-costs with acceptable efficiencies. The efficiency of amorphous silicon is 10% and cadmium telluride has efficiency between 15-20% (SETP, 2008). The third generation PV technology only exists in the research laboratories yet.

Solar energy technology can be applied in two possible areas. The technology can be used as PV panels on-site; this is small-scale electricity generation for households or small companies. The solar energy technology can be also used as concentrated solar power (CSP) on a large scale or utility scale.

4.2.2 Developments of solar-energy technology

The attention of the Dutch government for the development of sustainable energy technologies started after the first oil crisis in the seventies. The research on solar energy technology started in 1984 with the ISES program as the Dutch member of the International Solar Energy Society (ISES) (Verbong, van Selm et al. 2001). This program was performed at three Dutch universities and had two research themes. The research and development of crystalline gallium arsenide cells (GaAs) with a potential efficiency of 35-40% and of amorphous silicon (a-Si) cells that have low costs and an efficiency of 15-20% (Verbong, van Selm et al. 2001). The entrepreneurs started with manufacturing solar panels in 1980 within the Netherlands. These entrepreneurs were, for example, Holec Energy Systems, Stroomwerk and Zontec. The incumbent Shell entered the market with the company name Renewable Energy Systems in 1984 after taking over Holec Energy System (S1). Renewable Energy Systems became very active in the PV industry and formed joint ventures in the Far and Mid East, and in India. They also collaborated with Philips in solar electric power and lightning. In 1983 a Dutch solar trade association 'Holland Solar' was founded (Holland Solar, 2007). The companies and organizations active in the field of solar energy for small and large applications are the members of the association. The government has its doubts about solar energy because of the available sun hours in the Netherlands. However, the government launched in 1988 the subsidy program Support Regulation Energy Savings (SES) and Flow Energy in order to create a market for PV (Negro et all, 2009). The government formulated for the first time in the white paper on energy savings in 1990 the specific goal of the installation of 240 MWp of PV panels in the Netherlands. In this period ECN became more active in the research and development of solar panels. They started to cooperate with a large number of Dutch and foreign parties involved in solar energy technology. The ECN produced in collaboration with Renewable Energy Systems an industrial PV panel with an efficiency of 16% in 1994 (S3). Furthermore, several Dutch universities placed PV panels on house roofs (e.g. Amersfoort-Nieuwland, Barendrecht, Castricum and Heerhugowaard-City of the Sun) (Schoen 2001). The total capacity of installed PV has risen from 0,5 MW in 1976 to 1,3 MW in the year 1993 (DE, 1993). The expenditures on solar energy technology became the largest expenditure post for the research and development of sustainable energy technologies in the Netherlands (Verbong, van Selmet al. 2001). In 1997, the Renewable Energy Systems Company of Shell became Shell Solar Energy and different energy companies became active in the installation of PV panels like; PNEM, NUON and Eneco (S1, Mierlo 2006). Another Dutch solar panel manufacturer Solar Centre Amsterdam BV (SCA) also became active in this period. There also started different subsidized projects like the largest roof-integrated PV-system and ZonZeker in order to stimulate consumers to buy PV panels and boilers (S2). Shell Solar closed its PV plant in Helmond in 2002 and replaced their activities to North-America, Portugal and Germany (S1). This led to an enormous decrease of the production of solar panels in the Netherlands. The Dutch entrepreneurs continued their research and manufacturing activities and also concentrated on export markets such as Portugal and Germany. Since 2002, also other Dutch entrepreneurs started with manufacturing solar panels like Sunlab, Man Solar, Scheuten Sollar, Advanced Photovoltaic Applications BV (APA), and Solland Solar (S1, S2). The entrepreneurs exported their products also like Shell Solar. Their products do not contribute as a renewable energy source in the Netherlands because of the unfavourable and inconsistent regulations. The Dutch home market became unfavourable because of the inconsistent government policies like the delay of promised strengthening of energy performance standards, and the withdrawal of solar energy subsidies in 2003 (HollandSolar 2007). The annually installed capacity of PV dropped from 19,3 MW in 2003 to almost zero in the next three years (IEA 2007). Finally, the government launched after 2007 various programs for the implementation of PV panels in the Dutch home market.

4.2.3 Involved actors

Since 1984 large firms, entrepreneurs, electricity production companies, universities and research institutes were involved in solar energy technology. Different large firms with different skills and manufacturing histories are involved in the research and development of solar panels: the important large firms are Shell, Philips and Siemens. There are also Dutch entrepreneurs involved in the manufacturing of solar panels in the Netherlands. The involved entrepreneurs in the early phase are: Holec Energy systems, Stroomwerk and Zontec, and later, Sunlab, Man Solar, Scheuten Sollar, Advanced Photovoltaic Applications BV (APA), and Solland Solar (Negro et all, 2009). The PV panels were purchased by several actors, from electricity consumers to electricity producers. The involved electricity consumers are: households, residential project brokers and public buildings (S1). The involved electricity production companies are PNEM, NUON and Eneco. The involved research institutes are ECN, SenterNovem, and TNO. Furthermore, Dutch universities became involved like Eindhoven Technical University and Delft Technical University and Utrecht University. On the policy side, the Ministry of Economic Affairs was the major actor. They played a guiding and coordinating role in the development of solar energy technology. The characteristics of the involved actors are shown in table 7.

Table 7: Actors Solar energy technology

Actors	Characteristics
Government	Various policy programs
Research institutes	
TNO	Netherlands Organization for Applied Scientific Research
ECN	Energy research centre of the Netherlands
SenterNovem	Research institute of the ministry of economic affairs
Universities	
Eindhoven Technical University	Research and development of solar cell technology
Delft Technical University	Research and development of solar cell technology
Utrecht University	Feasibility studies on solar energy technology
Incumbents	
Shell	Manufacturer of solar cells and panels
Philips	Joint project with Shell
Siemens	Joint project with Shell
Entrepreneurs	
Holec Energy systems,	Manufacturer of solar cells and panels
Stroomwerk	Manufacturer of solar panels
Zontec	Manufacturer of solar panels
Solland Solar	Manufacturer of solar cells and panels
Scheuten Sollar	Manufacturer of solar cells and panels
APA (Advanced Photovoltaic Applications)	Research on solar panels
Electricity Consumers	
Households	Solar panels on house roofs
Residential Project brokers	Implementation on new buildings
Public utilities	Public utilities along roads
Public buildings	Local projects on public buildings
Electricity producers	

PNEM	Introduces of Green Currency
NUON	Plans for the future: 5% renewable in 2000, with a large share of PV.
Eneco	Heerhugowaard, Alkmaar and Langedijk start thinking about a 5 MW PV-project

4.2.4 Important historical events

The import historical events in the development of solar energy technology are chronological showed in table 8. The focus on solar energy technology started in 1984 with the ISES program and developed further until 2001. Entrepreneurs and incumbent firms started with manufacturing solar panels and there was also a niche market. The PV panels were in the first phase installed on summer houses and caravans and later on house roofs, public utilities along roads and public buildings. Since 2002, the solar energy system began to decline and the installed capacity of solar panels per year dropped nearly to zero. Shell Solar stopped their manufacturing activities in the Netherlands and other manufacturers sold their products on foreign markets. The developments of solar energy technology took place in the early transition phase.

Table 8: Chronological historical events solar energy technology

Events	Government	Manufacturers	Elec. production	Elec. consumers
1970- 1993	**Actions:** -1974: 1st Energy White Paper -1979: 2nd Energy White Paper -1984: ISES program (International Solar Energy Society) -1986: NOZ-PV programs (National Research Program on PV) -1988: SES program (Support Regulation Energy Savings and Flow Energy) **Goal**: - Energy white papers: installation of 240 MWp of PV modules in 2010 - ISES: start for fundamental PV research at 3 Dutch universities - 1st and 2nd NOZ-PV: R&D subsidies; development of PV technology -SES: Investment subsidies; compensation of 40% of the purchase costs of a PV system.	-Holec Energy Systems -Stroomwerk B.V. -Zontec -Renewable Energy System=> Shell by taking over Holec -Philips 1993: 1,3 MWp installed capacity	-not present	-Summer Houses -Caravans -House roofs
1994-2003	**Actions:** -1995: Stop SES program -1996: 3rd Energy White Paper -1996/2000: 3rd NOZ-PV program -1998: EPR program (Energy Performance Regulation) **Goal** -3rd Energy White Paper: 10% share of renewable energies in 2020. -3rd NOZ-PV: R&D and investment subsidies; more market oriented and focus on large-scale implantation of PV panels -EPR: Investment Subsidies for each installed Wp.	- Solar Centre Amsterdam BV 2003: 46 MWp installed capacity	-Nuon -PNEM -Eneco	- Large-scale House roof projects -Public utilities -Public buildings
2003-2010	**Actions:**	-Solland Solar	-Nuon	- Large-scale House

2003: EPR program stopped 2005: MEP program (Environment Quality of Electricity Production) 2006: MEP program stopped 2008: SDE program: Stimulation of Renewable Energy production **Goal:** MEP: limited investment subsidies SDE: limited investment subsidies	-Scheuten Solar -Shell Solar: closing of the PV plant in Helmond, activities in North-America, Germany and Portugal -APA B.V. 2008: 54 MWp installed capacity	-PNEM=Essent -Eneco	roof projects -Public utilities -Public buildings

The government developed also a lot of policies and programs to stimulate solar energy technology. The following solar energy programs were introduced: ISES program (1984-1988), SES program (1988-1995), 1st and 2nd NOZ-PV program (1986-1995), 3rd NOZ-PV program (1996-2000), EPR program (1998-2003), MEP program (2003-2006) and from 2008 the SDE program is still active (S1, S2, Negro 2009).

In the period 1984-1993, four research programs were introduced; ISES, SES, 1st and 2nd NOZ-PV programs. The goal of the ISES program was to gain theoretical knowledge about PV-technology. The 1st and 2nd NOZ-PV programs were introduced in order to promote the development of PV technology with R&D subsidies (S1, S2). The final program in this period was the SES program. This program was introduced in order to promote the development of the PV market with investment subsidies. There was a compensation of 40% of the purchase costs of a PV panel (S3). These programs led to the manufacturing of solar panels by entrepreneurs like Holec Energy Systems, Stroomwerk and Zontec, and the incumbent firm Shell. The incumbent Shell was active with the company name Renewable Energy Systems after taking over Holec Energy System (S1). The PV panels were installed on summer houses, caravans and some house roofs. At the end of the period 1,3 MWp of solar energy was installed (DE, 1993).
In the period between the years 1994-2003, two new programs started after the end of the previous programs. The 3rd NOZ-PV program was introduced between the years 1996-2000. This program was more market oriented than the previous NOZ-PV programs. The goal of this program was the removal of the bottlenecks and the realization of large-scale implementation of PV modules (S1). The second program was the EPR program introduced in 1998. This program was introduced in order to promote the market development with investment subsidies (S1, S2). The PV system buyers received 1,59 Euro per installed Watt (12,25 Euro cent per installed kWh) (Schaeffer, Seebregts et al. 2004). These programs led to the situation that the existing entrepreneurs became more active in the research and manufacturing of PV panels. Renewable Energy System became Shell Solar and opened a new production line for PV panels. Also the entrepreneur Solar Centre Amsterdam BV started manufacturing solar panels. In this period, electricity production companies became active for the first time in the solar energy system (Mierlo 2006). These companies were Nuon, PNEM and REMU. The developments in the solar energy system accelerated with the involvement of the various actors. There started many different solar energy projects; PV panels were installed on a large-scale on house roofs, public utilities and public buildings (S1). These projects can be seen as an attempt to create a mass market for solar energy technology in the Netherlands. These projects should lower the prices due the learning experiences and economies of scale. There was also active research and development of PV panels in order to reduce cost prices, improve the performance and the integration on buildings. The solar energy system developed enormous in this period and the installed capacity of solar energy increased further to 46 MWp in 2003 (DE, 2004).

In the period 2004-2010, the MEP and SDE programs started to stimulate the use of solar energy technology. The successful EPR program introduced in the previous period ended in this period. The EPR program was replaced by the MEP program (S1). The goal of this program was to stimulate the production of sustainable energy and was not a specific solar energy program. There were investment subsidies available; the PV system buyers received 6,8 Eurocents per installed kWh (SenterNovem , 2008). This subsidy was low in comparison to the EPR subsidy of 12,25 Eurocents per installed kWh. This was a very difficult regulation for the PV technology due the high costs of PV panels. The MEP program was stopped in 2006 by the Ministry of Economic Affairs. The official reason of the end was that the goal of 10% sustainable energy would be achieved without subsidies (S1, S2, Energie+ 2006). The end of the subsidy program damaged the trust of the actors in the PV sector in the Dutch government. There also started other entrepreneurs with manufacturing PV panels in this period. These entrepreneurs were Solland Solar and Scheuten Solar (S1, Stromen, 2004). An important event in this period was that Shell Solar closed its PV plant in Helmond and moved their activities to North-America, Germany and Portugal. The inconsistent and unfavourable policies of the Dutch government led also to the orientation of other entrepreneurs on foreign markets such as Spain and Germany. The manufactured PV panels became mainly export products and not sustainable energy technology that contributed to the Dutch energy supply. The entrepreneurs focused on foreign countries because of the growth of the worldwide PV market and to take advantage of foreign subsidies like high feed-in tariffs for PV (S1, S2). The government introduced the SDE program in 2008 after these events. There were very limited investment subsidies of 0,3-0,6 Euros per installed kWh available in this program. The annually installed capacity of PV dropped from 19,3 MW in 2003 to nearly zero in the next three years. The total installed capacity increased a little from 46 MWp in 2003 to 54 MWp in 2008 (IEA, 2007).

5. Specific patterns of relationships

In this part, the obtained results from the data will be analyzed. This part of this research aims to analyze the relational patterns between the actors involved in the transition towards the implementation of wind and solar energy technology. In both case studies the transition phase will be described first.

5.1 Case: Wind energy technology

5.1.1 The transition phase

The socio-technological development of wind energy technology is described in the previous chapter. The obtained results from the extended literature review and interviews show that the wind energy technology passed many developments. The transition of wind energy technology is nowadays at the end of the acceleration phase (see fig 6).

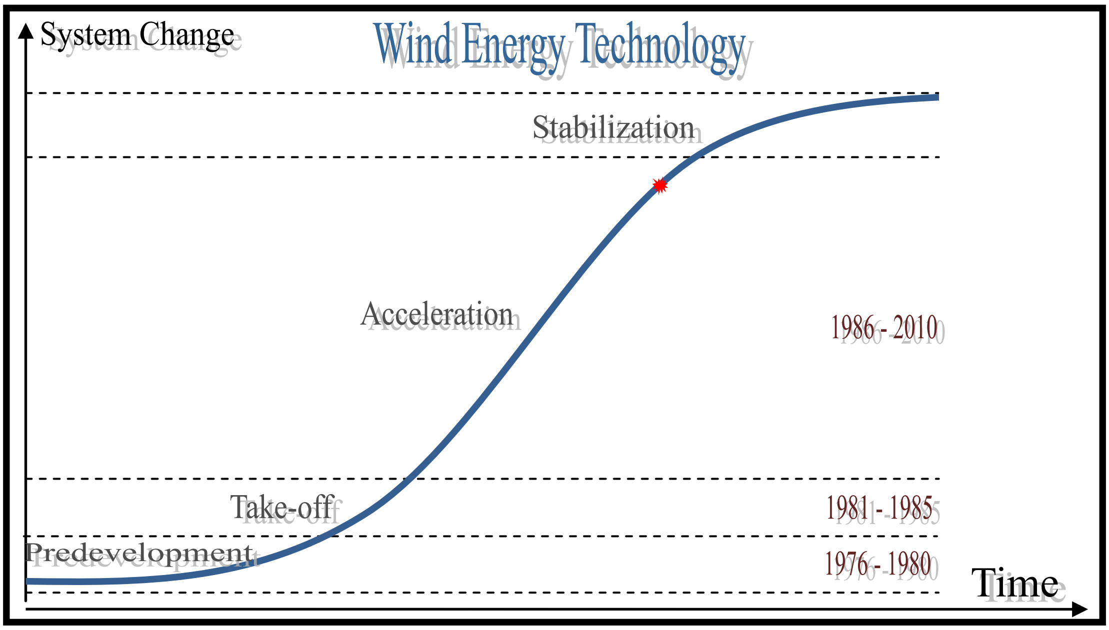

Fig. 6: The transition curve of wind energy technology

The developments between the years 1976-1980 are allocated in the predevelopment phase. This phase is characterized by the emergence of wind energy technology. Research on wind energy technology was started by the universities and research centres. The small and large firms experimented with different technical forms like the VAT and HAT wind turbines. These actors tried to find the best design and to break the resistance of electricity production companies to change (W3).

The period between 1981-1985 is the take-off phase in the transition of wind energy technology. There were three large firms and around ten entrepreneurs active in the production of wind turbines. The wind energy technology became also more interesting for the electricity production companies, nearby farmers and energy enthusiast (W1). This phase is characterized by the emergence of a dominant design for wind turbines. In this period, the VAT became the standard design for wind turbines

A long period between 1986-2010 is allocated in the acceleration phase of the transition process. The shake out of wind turbine producers took place in this period. The remaining three Dutch wind turbine producers also disappeared from the Dutch home market after the entry of foreign wind turbine producers on the Dutch market. Only Vestas and Siemens stayed as important wind turbine producers in the Netherlands (W2). The wind turbine technology improves and multi MW turbines are produced. Also many wind energy projects started and wind energy technology became a fact in the Netherlands. The wind energy technology became the past three years a serious alternative in the energy market (W3). Wind energy technology did not replace the old regime but is an addition in the production of electricity. The current technological changes of wind turbines are incremental and build on economies of scale. The socio-technological developments of wind energy technology can be thus placed at the onset of the stabilization phase in the transition process.

5.1.2 Patterns of relationships

In the most favourable situation of the transition process, all relations between the actors are present. There are three major actors (technology producers, technology users and the government) considered in this pattern of relationships. The technology producers are divided in two sub actors, the fossil fuel and wind energy technology producers. The latter actors can be seen as entrepreneurs and the former actors as large firms that only focus on the development of their technology. The second major actor is the group of technology consumers. The technology consumers consist of electricity producers and electricity consumers. These sub-actors are also related to each other. The last considered major actor is the government. It can influence the relation patterns in the transition process via their policies. Policies can be regarded as regulations of processes and systems that lead to innovation and diffusion of sustainable technologies. These policies affect the relations between the production and consumption sub-actors depicted below in figure 7.

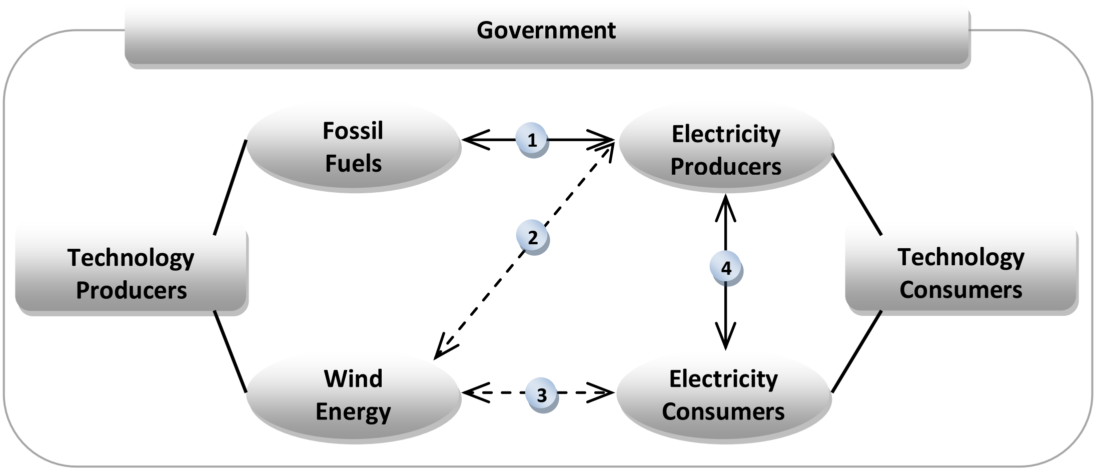

Fig. 7: Ideal patterns of relationships, Wind energy technology

In the conventional system, the relations are between the fossil fuel technology producers and electricity producers **(1)** and between electricity producers and electricity consumers **(4)**. In the conventional system there are no direct relations present between fossil fuel technology producers and electricity consumers. In the sustainable energy system, the relations are between the wind energy technology producers and electricity producers **(2)** and between electricity producers and consumers **(4)**. In this system, there are also direct relations possible between the wind energy technology producers and electricity consumers **(3)**. There are thus two possible pathways for the consumers to get sustainable energy; from the producers of wind energy technology and from electricity production companies.

In the predevelopment and take-off phases of the transition process, all relations between the actors were present (see fig 8).

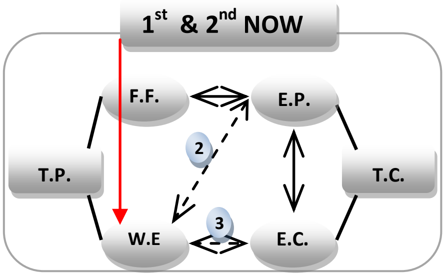

Fig. 8: Relations predevelopment and take off phase, Wind energy technology

The government played an important role in the technological development of wind energy technology. They launched the following programs (BEOPb):

- 1976-1980: 1st NOW program.
- 1981-1985: 2nd NOW program.

In these programs, research and development subsidies were made available after approval by the ministry of Economic Affairs for Dutch manufacturers. The government actions led to an increase of the knowledge and manufacturing skills of the small and large scale wind turbine manufacturers. It made also the following relations between the involved actors available.

The relation between the wind energy technology producers and electricity consumers **(3)** was present in this phase. The wind turbines were first only purchased by farmers living in the neighbourhood and small energy intensive companies (Wind Service Holland, 2000). The number of wind turbine buyers increased in this period because of the financial compensation regulations for wind turbines. Consumers are thus able to produce sustainable energy directly after purchasing the technology created by the entrepreneurs.

The direct relation between the wind energy technology producers and electricity producers was present **(2)** but not strong in this phase. The electricity producers were not very enthusiast about wind energy and purchased only a few wind turbines. This is because the wind turbines were not so far developed. Then, the capacity of wind turbines was limited and there were many technological problems.

The relationship patterns between the most important actors in the development of the wind energy sector changed a lot in the acceleration phase. In the predevelopment and take/off phase all the relations between the actors were possible. There were Dutch wind turbines manufacturers like entrepreneurs and large firms and wind turbine buyers like the electricity production companies and farmers/households available. In the acceleration phase, the relation between the electricity consumers and technology producers **(3)** vanished because of the focus on large-scale wind turbines. Now, the electricity consumers can only purchase wind energy from electricity production companies (see fig 9).

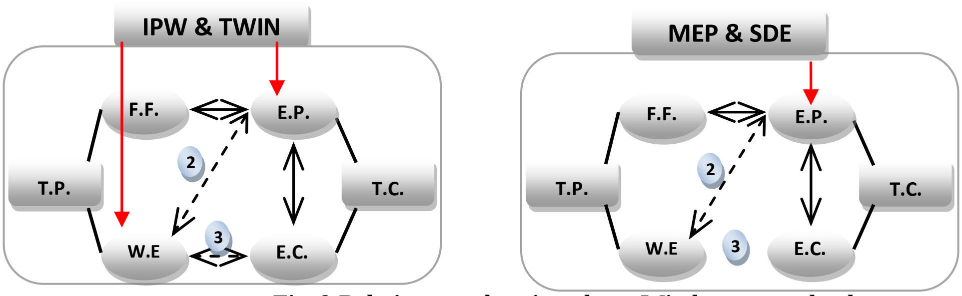

Fig. 9:Relations acceleration phase, Wind energy technology

The government played a crucial role in the development of the relationship patterns of wind energy technology in the Netherlands. The responsible government agency is the Ministry of Economic Affairs. The Directorate General of Energy played a guiding and coordinating role in the development of wind energy programs and subsidies (G1). The government developed also a lot of policies and programs in the acceleration phase in order to stimulate the production and use of wind energy technology in the Netherlands. The following wind energy programs were introduced in this phase (W3, G1):

- 1986-1990 IPW program
- 1991-2000 TWIN program
- 2003-2005 MEP program
- 2008-2010 SDE

These programs can be distinguished in two parts. The IPW and Twin programs were R&D and investment subsidies oriented. The MEP and SDE programs were only investment subsidies oriented. (G1) There is no relation present between the electricity consumers and technology producers **(3)** after the end of R&D subsidies. The government presented not sufficient continuity in their stimulation programs. This led to many uncertainties for the wind energy technology producers. The development of policies and supporting mechanisms for wind energy depended largely on the political preferences of the government of the Netherlands. The preferences of the governments in their reign determined the available budget for the development of wind energy. Until 2000, there are R&D subsidies available but small product improvements or efficiency improvements are not supported by the government. After the year 2000 only investment subsidies were available. So, incremental product improvements necessary to keep up with foreign producers became impossible. Consequently, the Dutch wind energy technology producers reached a competitive disadvantageous position and ultimately in 2000 went bankrupt. Another main obstacle induced by the government is the many changing programs, i.e. the inconsistency of governmental policies.

In this phase, there is a strong relation between the wind energy technology producers and the electricity producers **(2)**. The electricity producers became involved in the development of large scale wind parks on the land and sea(W2). The wind energy market was 20 years ago much smaller, offshore wind energy production did not exist and the small turbines were not very well developed (W3). The major electricity production companies did not have much interest in small wind turbines but were interested in large wind turbines. Today, the wind turbines are technologically much better and turbines with large capacities are available (W2). There are also offshore wind turbines developed in the Netherlands that receive interest from electricity producers. Another event in this phase is that on the wind energy technology production side only foreign manufacturers were left. In the year 2000, the Dutch wind turbine manufacturers ended their activities after the appearance of foreign wind turbine manufacturers on the Dutch market.

The patterns of relationships between the actors involved in the transition to wind energy technology changed between the years 1986 and 2010. In the predevelopment and take off phase the wind energy technology was a substitution for the fossil fuel based energy regime. The electricity consumers were able to purchase wind energy technology directly from the wind energy technology produces (see fig. 8; relation 3). The wind energy technology was thus a competitor for the electricity production companies. They were mainly based on fossil fuel based energy. The wind energy technology was thus a substitution product for the fossil fuel energy technology in the transition process. In the acceleration phase, the patterns of relationships between the actors involved changed due the governmental programs (see fig. 9). In this phase, the electricity users were not able to purchase wind energy technology directly from the wind energy technology producers. See figure 8, the relation between wind energy technology producers and users **(3)** disappeared. The wind energy technology was not more a competitor for the electricity production companies. It became an additional product for the fossil fuel based energy technology in the transition process. This led to the faster adoption of the wind energy technology in the existing fossil fuel technology system.

5.2 Case: Solar energy technology

5.2.1 Transition phase

The socio-technological developments of the solar energy technology are also described in the previous chapter. The results from the extended literature review and interviews show that the solar energy technology did not pass the transition phase yet. The transition of solar energy technology is at the end of the take-off phase of the transition process.(see fig 10).

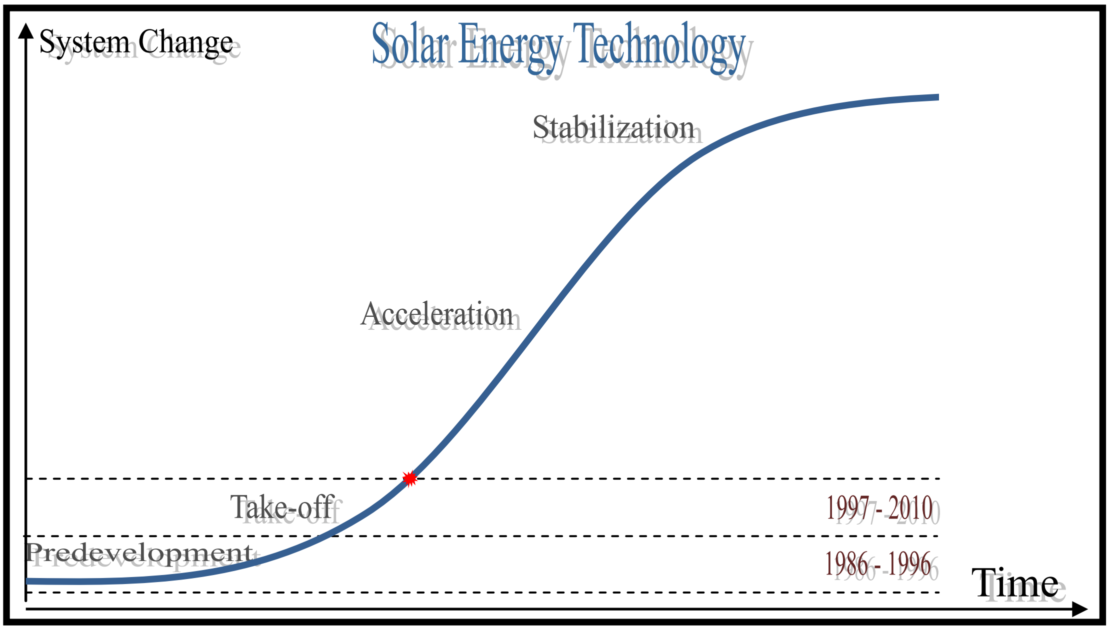

Fig. 10: The transition curve of solar energy technology

The developments between the years 1986-1996 are allocated in the predevelopment phase. This phase is characterized by the emergence of solar technology. The R&D on solar energy technology in the Netherlands started in the year 1986 with the National research program PV (NOZ-PV) (S1). The technological development of solar cells progressed very well in the Netherlands. There were important actors like Senter Novem, ECN, Ecofys and Eindhoven Technical University and Delft Technical University present in the technological development of solar energy technology. These actors were constantly involved in the development of solar energy technology. The technological development can be divided in two parts; 40% development of solar cells and 60% development of solar panel systems en inverters (S1).

The period between 1997-2010 is the take-off phase in the transition of solar energy technology. There are around ten solar cell technologies developed; some are in the research phase and some are already produced. The most developed solar cells are mono/poly crystalline silicon and amorphous silicon solar cells (S2). These three solar cells are the most commonly used technologies. Solar cells are until 2003 only produced by Shell Solar in the Netherlands. Shell Solar sold first their activities in the Netherlands and after a while they stopped all activities. After 2003, two other Dutch manufacturers Solland Solar and Scheuten Solar became active in the production of solar cells and solar panel systems (S1). These companies are still producing solar cells and panels but they are not active on the Dutch home market. The development of new solar panel systems and inverters is also present since 2003 in the Netherlands. The technology of solar cells in the Netherlands is still improving but there has been no many market introduction of solar panels in the Netherlands. The production of solar energy technology and the 'know how' is very strong in the Netherlands (S3). The socio-technological development of solar energy technology can be thus placed on the end of the take-off phase of the transition process.

5.2.1 Pattern of Relationships

The patterns of relationships between the most important actors in the development of the solar energy sector are shown in figure 11. The solar energy system in the Netherlands is in the take-off phase of the transition. There has not yet been a change in the relationship pattern. All relations between the involved actors are still present. There are still Dutch PV panel manufacturers like entrepreneurs and large fossil fuel energy technology firms and solar panel buyers like electricity production companies and households available.

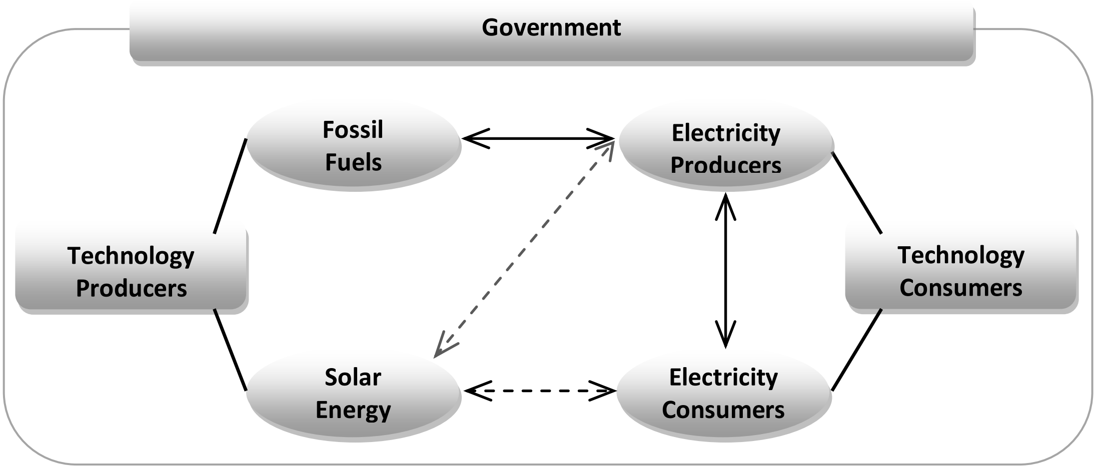

Fig. 11: patterns of relationships, solar energy technology

The government played also a crucial role in promoting the development and use of solar energy technology in the Netherlands. The responsible government agency is the Ministry of Economic Affair (EZ)s and the Ministry of Housing, Spatial Planning and the Environment (VROM) (G1). They have the guiding and coordinating role in the development of solar energy programs and subsidies. The government developed also a lot of policies and programs to stimulate solar energy technology. The following solar energy programs were introduced (S1, S2):

- 1986 - 2003 1st , 2nd and 3rd NOZ-PV program: Min. EZ; R&D and Investment subsidies.
- 1997 - 2000 PV Covenant: Min. EZ; investment subsidies for collaborated projects.
- 1998 - 2003 EPR program: Min. VROM; investment subsidies
- 2003 - 2005 MEP: Min.EZ; investment subsidies for only electricity production companies
- 2008 - 2010 SDE: investment subsides; max vol. 20 MW per year

The long term R&D subsidies focusing on the development of new solar cell technologies are well organized in the Netherlands. There were always long term R&D programs and subsidies present (S3). The NOZ-PV programs between 1986-2000 were R&D subsidies oriented (see fig 12). The NOZ-PV programs were successful governmental programs. They invested a lot in the R&D of solar energy technology (S1). The programs after the NOZ-PV program were mainly investment subsidies for solar energy technology buyers.

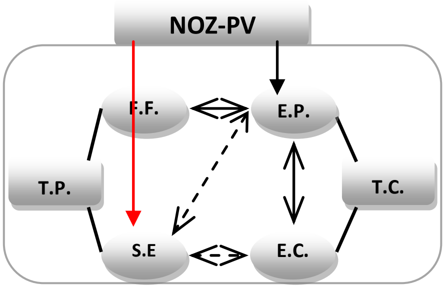

Fig. 12: Relations predevelopment phase, Solar energy technology

The PV covenant and the EPR programs were also very successful. These programs led to an increase of the total installed capacity of solar energy in the Netherlands (S1). Remarkable is that in the years 1998,1999 and 2000 three subsidy programs, i.e. 3rd NOZ-PV, PV Covenant and the EPR program were available at the same time (S1,S2). There were also financial stimuli available from the electricity production companies for consumers. This led some organizations and individuals to make abuse of the available subsidies (G1, S2). The EPR program is also not very well monitored by the government in the years 2001-2002. There were far more subsidies granted than the reserved budget. The EPR program stopped immediately when the government found out of the abuse and the too many granted subsidies. The PV Covenant is also not extended because the too high demands for financial stimulations of the industry.
Another missing point is the short term subsidies for exploration or products that are almost ready for the market but still expensive (S3). This can be seen as a major obstacle in the Netherlands. The investment is too large for small producers; they don't have enough financial resources, specialized equipment and demonstration plants. After the end of the EPR program, the MEP program started in the year 2005. The MEP and SDE programs made only investment subsidies available(see fig 13).

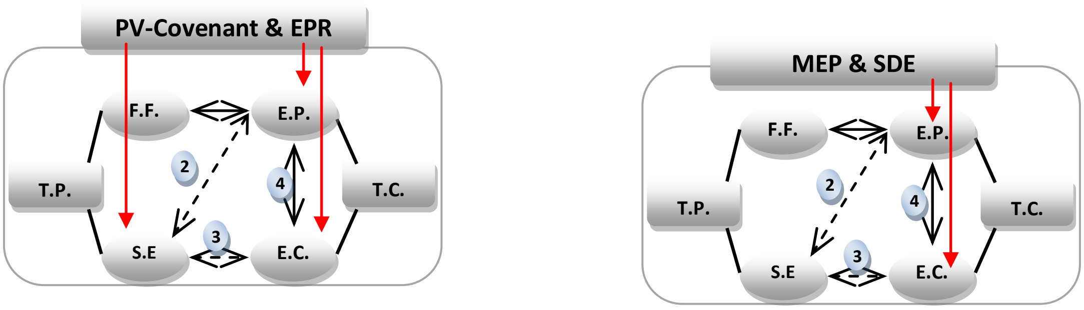

Fig. 13: Relations take-off phase, Solar energy technology

The government had not a very good impact on the transition and relations between the actors in solar energy technology in the Netherlands. The different investment subsidy programs were not coordinated with each other and not well monitored. The industry and consumers made abuse of the ignorance by the government that led immediately to the end of the subsidy programs in the year 2003.

The relations between the solar technology producers and technology consumers are present **(3)** but not so strong. On the technology production side, there is a worldwide tremendous competition among solar cell and system producers. In the Netherlands, only Shell Solar was active until 2003. A few companies started with manufacturing solar panels after Shell stopped its activities. So, there was no competition present between incumbents and entrepreneurs in the solar energy sector. The solar panel manufacturers did have relations with the electricity production companies **(3)** and the electricity consumers **(4)**. There are different roof projects with solar panels realized in the Netherlands, among others, a large scale roof project in Nieuw Sloten. This was the first solar energy project at an urban scale worldwide (S2). The PV panels were owned by the electricity company NUON. Another PV project was in Nieuwland (S2). There were also PV panels installed on house roofs, but this time it was owned by the house owner. The relations between the technology producers and technology users **(2) (3)** depends largely on the financial stimulations by the governments. The governmental regulations changed a lot in the solar energy sector and therefore not the pattern but the strengths of the relations fluctuated a lot.

5.3 Cross-case study results

In this part, a cross-case analysis of the transition to wind and solar energy technology will be performed. The similarities and differences in the pattern of relationships between the wind and solar energy technology will be identified.

Since 1975, large firms, entrepreneurs, electricity production companies and electricity consumers were involved in wind turbines. The major electricity production companies did not have much interest in small wind turbines but were interested in large wind turbines. There was a weak relation between the technology producers and technology users in this phase. After 1985, the number of wind turbine buyers increased because of the introduction of investment subsidies for wind turbines. These buyers were private and institutional investors and electricity production companies. The relations between the technology producers and the electricity production companies and users improved and they became more involved via a lot of contracts. Despite of the developments of the large scale wind turbines, the incumbents stopped their activities. The many design and manufacturing problems, large financial risks and the small home market led to the end of the activities regarding the large scale wind turbines produced by the incumbents. After 1990, The small wind turbine manufacturers changed their strategy to stay in the market and became large scale wind turbine manufacturers. Another change in this period was the arrival of foreign manufacturers on the Dutch market. The cost of change and technology development became too high for the Dutch entrepreneurs and the enormous competition of foreign manufacturers led to the end of the Dutch wind turbine manufacturing in the year 2000. Today, the wind turbines are technologically much better and turbines with large capacities are available. There are also offshore wind turbines developed in the Netherlands that receive interest from electricity producers. However, on the wind energy technology production side only foreign manufacturers are left.

In the solar energy technology only Shell Solar was active in the production of solar cells and panels until 2003. On the technology production side, there is a worldwide tremendous competition among solar cell and system producers. A few companies started with manufacturing solar panels after Shell stopped its activities. So, there was no competition present between incumbents and entrepreneurs in the solar energy sector. The solar panel manufacturers had relations with the electricity production companies and consumers. The relations between the technology producers and technology users depended largely on financial stimulations by the government. The governmental regulations changed a lot in the solar energy sector and therefore the strength of the relation is weak.

In general, the similarities in the patterns of relationships of wind and solar energy technology actors are that there were no relations between the entrepreneurs and incumbents. Remarkably in both cases the incumbents dominated in the predevelopment phase. In the wind sector ´Stork, Fokker and Holec´, and in the solar sector ´Shell Solar´ were the dominating incumbents in each sector. In both cases, the entrepreneurs significantly began to enter the market when the incumbents stopped their activities. There were also no any interactions between the entrepreneurs. They did not intend to cooperate because they competed with one another and did not trust each other.

In both cases, the entrepreneurs suffered from the negative effects of the changing and inconsistent governmental programs. The long term R&D subsidies for the development of new wind turbines and solar cell technologies were well organized in the Netherlands. There was always long term R&D programs and subsidies present. However, there are no short term subsidies for exploration or improvements of products that are almost ready for the market but still expensive. This can be seen as a major obstacle in the Netherlands. There are many regulations present for R&D; the companies or institutions get 60% of the R&D costs subsidized. But small improvements of the technology for further commercialization are only for 20% subsidized (S3, W2). The required investments are, however, too big for small producers, which don't have financial resources, specialized equipment and demonstration plants. They only get 20% of these large investments subsidized by the government. This resulted in that entrepreneurs could not sufficiently commercialize their developed products. They could also not react to the demand in the market and the requirements of users. Consequently, the entrepreneurs are limited in the technological development of their products by the implemented governmental policies. Furthermore, the potential users also face extra uncertainty about the performance of the sold technology

The investment subsidy oriented governmental programs for wind energy technology changed a lot. The Dutch government was also actively steering the technology development. Business plans of wind turbine manufacturers had to be approved by the ministry to get research subsidies and owners of wind turbines had to be certified in order to receive investment subsidies. The amount of subsidies was, however, decreased every year. The investment subsidy programs were not consistent and changed a lot because of the rising costs of the programs. So, the conditions for the development of the Dutch home market were not very well. This led to a lack of experience and manufacturing skills at the entrepreneurs. The conditions for foreign wind turbine manufacturers, however, were much better. Foreign wind turbines were better than Dutch wind turbines when they entered the Dutch home market. In the year 1993, the market share of Dutch wind turbine manufacturers was 98%, which decreased to 41 % in 1997. The enormous competition of foreign manufacturers with better wind turbines led to the end of the Dutch wind turbine manufacturing.

The different investment subsidy programs for solar energy technology were not coordinated with each other and not well monitored. The industry and consumers also made abuse of the ignorance of the government, which led to the immediate end of the subsidy programs in the year 2003. The inconsistent and unfavourable policies of the Dutch government led also to the movement of entrepreneurs to foreign countries such as Spain and Germany. The manufactured PV panels became mainly export products and not sustainable energy technology that could contribute to the Dutch energy supply. The entrepreneurs focused on foreign countries because of the growth of the worldwide PV market and to take advantage from foreign subsidies like high feed-in tariffs for PV. The end of the subsidy programs led to the shift of the entrepreneurial activities to foreign countries. Therefore, the main conclusion of this report is that in order to support the production and use of wind and solar energy technology, there need to be continuous and simultaneous long term R&D and commercialization programs in place.

6. Discussion

In this section, the performed research will be discussed. The theoretical framework, the methods applied, and the results obtained in this study will be discussed. In order to evaluate the research, important aspects to be addressed are the reliability and the validity of the research approach (Yin, 2003). Reliability is the degree to which other researchers achieve similar results when they follow the same procedures and case studies. Validity is the extent to which the research addresses the specific subject that the researcher tries to study.

The patterns of relationships between the involved actors in the solar and wind energy technology are analyzed according to the theoretical background of transition processes. The transition theory used in this report is mainly based on the theoretical perspective of Geels (2002, 2005) on socio-technological transitions and the multi-level perspective. Geels applied his theoretical perspective on the transition of personal transportation (2002) and land-based road transportation (2005). Scientific articles about socio-technological transition in solar and wind energy technology have not been published yet. The use of the theoretical perspective of Geels in both the wind and solar energy case needs to be discussed. According Geels (2002, 2005), his theory deals with transitions at the level of societal functions such as housing, transportation, communication, energy supply. He also states that societal functions are fulfilled by socio-technical systems that should consist the following elements: technology, user practices, regulations, markets, cultural meaning, infrastructure, maintenance and supply networks (Geels, 2002 & 2005). The transition theory of Geels is thus more suitable for a system approach and not for an organizational approach. Accordingly, this theory fits for the analysis of transition in the wind and solar energy technology systems. Furthermore, all of the stated elements of the societal functions in a system approach are present in the transition of solar and wind energy technology. Therefore, the wind and solar energy cases are suitable for a socio-technical analysis of the transition of these technologies.

In this study, it is important to document the research method in order to improve the reliability and validity of the results. The research method starts with building a narrative of the developments of wind and solar energy technology and their utilization in the Netherlands. Important historical events derived from extensive literature review and interviews with experts were used to build these narratives. The reliability of the case studies increases when collected data from multiple sources are used (Yin, 2003). In this research data from an extensive literature review and multiple interviews with experts are used. Various articles are used to compare the information with each other. The validity of this research increases because data from interviews with experts are used to validate the data and add missing information from the literature review. For example, the governmental subsidy programs were found in the literature but the interview with experts added more detailed information why some programs stated and stopped. In the analysis of this report, interviews are the most significant sources of gathered information. An interview summary is written for each interview with experts. A significant type of validity in an exploratory research is construct validity. This is that the studied concepts are measured on correct operational indicators (Yin, 2003). The main concept in this research is the pattern of relationships between the actors involved in both cases. The reason for a multiple case design is that a multiple case design is a more robust design than a single case design. It provides more precise explanation of relationships and more reliable theoretical propositions. This research is limited to two case studies because every case should be individually analyzed, which is very time consuming. In order to operationalize this concept, an overview of the socio-technological developments of the wind and solar energy technology is described on the basis of a literature review. This formed the basis for the initial model of the pattern of relationships between the actors involved. Then, the relations between the involved actors and the possible influencing factors on these relationships were defined. The patterns of relationships are analyzed on the basis of the information from the interviews with experts and the extensive literature review. According Yin (2003), the validity of a study increases when multiple sources of data are used.

The results of this study can also be compared with the results of previous studies. This can be done for a research with the same theoretical approach with other cases. For example, Geels (2005) has analyzed land based road transportation with the socio-technological transition theory. Geels conclude mainly that system innovations take place though the relation between technology and society. He also states that the emergence of new regimes comes from multiple developments that link and reinforce each other. This study shows also that the relations between different actors are important in the development of wind and solar energy technology. And that the new regime is not successfully developed because of the disruptive relations between technology and society.

The results of this research can also be compared with studies applying another theoretical approach to the same cases. Kamp (2002) analyzed the wind energy technology and Negro et al (2009) analyzed the solar energy technology, both with different approaches. Kamp (2002) analyzed the effects of learning in the development of wind energy technology and compared the Netherlands with Denmark. Negro et al (2009) analyzed the solar energy technology innovation system in the Netherlands. The results in this research correspond largely with the result of Kamp and Negro et al. Also, the obtained information from interviews was crucial for this research. The information from the interviews also largely corresponds with the data used in the articles of Kamp (2002) and Negro et all. (2009). The similarities are for example the many changing governmental programs and the encountered problems by the technology producers in the wind and solar energy technology sector.

7. Conclusion and policy implications

The central aim of this research is to gain a better understanding of the relations between the technology producers and users in the development of wind and solar energy technology within the Netherlands. The focus in this research was on the socio-technological developments in the wind energy technology. The expectation was to derive lessons for the future developments of solar energy technology from the developments of wind energy technology in a later stage. This research is done in order to answer the following research question.

How did the relations between the entrepreneurs, incumbent firms, technology users and government develop in the technological transition to wind and solar energy technology within the Netherlands?

The answer to the research question can be explained with figure 14. Direct relations as well as indirect relations via the government are possible between the entrepreneurs and incumbents.

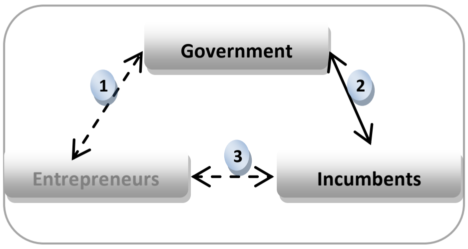

Fig 14: Relations entrepreneurs, incumbents and government in the predevelopment phase.

In the take-off and predevelopment phase of the transition to wind and solar energy technology only incumbents are present (see fig 14.). The entrepreneurs are thus not present when the technology starts to develop. So, there exists no direct relation between incumbents and entrepreneurs **(3)**. The incumbents are supported by the government with R&D and commercialization subsidies **(2)**. In this phase, the government doesn't support entrepreneurs **(1)**. Therefore, there is no indirect relation via the government present between the incumbents and entrepreneurs **(3)**.

In the acceleration phase of the transition to wind and solar energy technology only entrepreneurs are present (see fig 15).

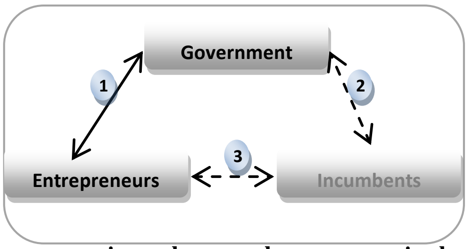

Fig 15: Relations entrepreneurs, incumbents and government in the acceleration phase.

The incumbents stopped their activities regarding the development of wind turbines and solar panels. Therefore, there exists also no direct relation between the entrepreneurs and incumbents **(3)** in the acceleration phase. The entrepreneurs are now supported by the government with R&D and commercialization subsidies **(1)** after incumbents ended their activities **(2)**.

In both cases, the incumbents dominated the market in the predevelopment phase of the technology and the entrepreneurs only significantly enter the market when the incumbents stopped their activities. The entrepreneurs step in too late in a technological field abandoned by the incumbents due to unfavourable commercialization prospects. This is because, when the incumbents leave, the government starts to subsidize entrepreneurs but not in a consistent way due political preferences. Consequently, the entrepreneurs start-up at a technological distance (lagging behind) with respect to foreign competitors with more advanced and better products.

It can be concluded for both cases that there need to be more continuous long term R&D and commercialization programs for entrepreneurs as well as incumbents in order to support the production and use of wind and solar energy technology. However, there is also a controversy between the industry and the government about the many changing programs. The industry states that they have suffered from the negative effects of the changing and inconsistent governmental programs. The government states that they have immediately stopped governmental programs when they found out of the abuse and the too many granted subsidies to the industry.

The remarkable point in this research is the presence of the incumbents in the early development phase of each technology and the start up of entrepreneurs after the incumbents stopped their activities. Therefore, further research should concentrate on:

'Why only incumbents are involved in the beginning stages of wind and solar energy technology'?

Further research should aim at finding out why only incumbents are involved in the early phase of technological development and their possible influence on the government.

It is important to note that the government needs to play a promoting role in the use and production of wind and solar energy technology in the Netherlands. Until now, this is done via various governmental programs in the form of R&D and investment subsidies. Encouraging renewable energy is important because it promotes the deployment of wind and solar energy technology. The use of renewable energy technologies also improves the experience and skills that leads to lower prices through learning effects. This encourages the competitiveness of renewable energy technologies.

The European goal is 14% and the Dutch goal is 20% for the production of renewable energy in the year 2020. The current production of renewable energy is around 4% in the Netherlands. There needs to be done a lot in order to reach the goals of 14% or 20% in 2020. Despite of the inconsistencies of governmental subsidy programs, the form of the policy might be not ideal. The current form of policies is subsidies. Much more attention could be spent on communication channels. For example, there is no clear information available about wind and solar energy. A clear statement by the government favouring the promotion of wind and solar energy is still missing. Furthermore, promotion, advertisements and marketing of wind and solar energy also does not exist. Another mechanism that the government could use are obligations or changes of regulations. The implementation of solar and wind energy can be prescribed for residential project brokers and electricity production companies. This can be accomplished by changing current regulations. Finally, the source of subsidy for renewable energy could be changed. Currently, the allowed subsidies come directly from the budget of the government. The subsidies for sustainable energy technologies can also be financed from tax regulations on electricity produced from fossil fuels. This should then not be called a subsidy but an environmental tax or renewable energy production contribution. Summarized the following mechanisms should be improved to stimulate the production and use of solar and wind energy technology:

- Clear position of the government.
- More use of communication channels.
- Changing regulations and obligations.
- Subsidies derived from taxes on fossil fuel based energy consumption.

Despite of all these supporting mechanisms, the most important criterion is continuity. If the government does not change its vision after every election and can offer continuous programs then the production and use of sustainable energy technologies will improve considerably. It will make long term strategic planning available for technology producers, electricity production companies and users.

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9. References

9.1 Interviews

Wind energy technology

(W1) Linda Kamp: Assistant professor of wind energy at TUD
(W2) Paul van der Oosterkamp: Group leader renewable energy at ECN
(W3) Gijs van Kuijk: Professor/Scientific Director Duwind at TUD

Solar energy technology

(S1) Ronald van Zolingen: Professor Solar energy technology at TUE/ ex Senior Business Advisor Shell Solar).
(S2) Jadranca Cace: Owner Rencom/ ex product manager renewable energy at Nuon
(S3) Paul van der Oosterkamp: Group leader renewable energy at ECN

Governmental policy

(G1) Willem van der Heul (Senior policy advisor renewable energy at Ministry of Economic affairs)

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