Dynamics of Technological Innovation Systems

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Dynamics of Technological Innovation Systems

The Case of Biomass Energy

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Prologue

This PhD project is carried out as part of a larger research programme called 'BioPUSh' (i.e. Integrated Strategies for Identifying optimal Bio-energy Production & Utilization Systems), financed by NWO-NOVEM Energy Research Programme. In this programme, three PhD projects and one Post-Doc project are carried out, aiming to contribute to the identification of biomass systems that can result in (the successful implementation of) cheaper biomass energy and more efficient land use. Hereby, BioPUSh focuses on several innovative concepts of biomass production and use, which are multiple land use, multi product crops, and cascading. The corresponding research questions of the BioPUSh programme are the following:

i. What are promising multi-functional bio-energy systems that can result in cheaper energy and more efficient land use, and how do these systems relate to costs, Green House Gas emissions, energy, and land use efficiencies?
ii. What are the economic interactions between large-scale application of multifunctional biomass systems and prices of land and competing products within the context of the European agricultural policy?

However, in order to successfully implement these multifunctional biomass systems, it is important to identify potential implementation barriers and drivers, and to advise policy makers on how to overcome or stimulate these barriers and drivers. Two sub-questions in BioPUSh refer to this aspect:

i. What potentially successful strategies could actors develop in order to simulate innovation, diffusion, and implementation in multi-functional bio-energy systems?
ii. What are the main barriers and incentives that influence the widespread introduction of multi-functional bio-energy systems and how can these be removed or stimulated by interventions of actors and, more particularly, by governmental policy?

This PhD project will try to contribute to answer these questions by analysing historical trajectories of biomass energy technologies. Whereas the other projects of the programme focus on technical, ecological, micro and macro-economic aspects, this thesis will concentrate on the social aspects.

1 Introduction

1.1 Background

In order to sustain economic growth, our economy strongly depends on large amounts of fossil fuels[1] such as oil, natural gas, and coal. These fossil fuels have several negative effects on the environment, among which local air pollution and climate change. Therefore, for several decades, (inter)national governments have made plans to reduce the economy's dependency on fossil fuels by the substitution of alternative energy sources such as renewable energy sources. Renewable energy sources are defined as any energy resource, naturally regenerated over a short time scale and derived either directly from the sun (such as thermal, photochemical, and photoelectric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy). Renewable energy does not include energy resources derived from fossil fuels, waste products from fossil sources, or waste products from inorganic sources (IEA 2006). These energy sources contribute to the diversification of energy carriers for the production of heat, fuels, and electricity. They improve access to clean energy sources, they reduce pollution and emissions from conventional energy systems and, furthermore, they reduce the dependency on fossil fuels. Examples of such sources are biomass energy, wind energy, direct use of solar energy, hydropower, marine energy, and geothermal energy (Turkenburg 2000; IEA 2006). In 2000, the share of renewable energy sources in the total global energy demand was about 13.3% of the total energy supply (IEA 2002b). However, for western economies this share was much lower: 6.2% of the total energy supply in OECD countries compared to 22.4% in non-OECD countries (IEA 2002b).

The current situation of large fossil fuels dependency and the hampered breakthrough of renewable energy sources and associated technologies is accurately described by the term *'carbon lock-in'* (Unruh 2000). It represents the problematic situation for alternative energy sources to break through, due to having to compete with an incumbent technological system based on fossil fuels that benefits from long periods of experience, leading to high efficiency, low costs, optimal institutional arrangements, and many vested interests (Unruh 2000).

Renewable energy technologies can be labelled as radical innovations. For radical innovations to be successful, they have to overcome considerable barriers among which prevailing standards. Furthermore, they have to compete with the network externalities of established products or technologies (Markard and Truffer 2006). In their early phases of development, these innovations are still inefficient, crude, and badly tuned to the characteristics of the incumbent system. Therefore, they cannot immediately compete successfully with established technologies (Rosenberg 1976), and diffusion will be slow.

The carbon lock-in phenomenon partly explains the low share of renewable energy sources in western economies in spite of numerous government actions to increase the share of renewable energy sources. A relevant question, therefore, is how to break through the current situation of carbon lock-in, in order to accelerate the diffusion of renewable energy technologies in society. To answer this question, it is necessary to open the black box of carbon lock-in, and to analyse in a detailed manner how the development and diffusion of renewable energy sources take place. Such an analysis should allow us to pinpoint key mechanisms that block or induce the development process. Insight into these mechanisms is necessary to design policy arrangements that may effectively deal with these inducement and blocking mechanisms, as to speed up the diffusion process of renewable energy sources.

For opening the black box and analysing the development and diffusion process of renewable energy sources, many different perspectives can be used. This thesis focuses on the perspective of the introduction of a renewable energy technology as an innovation.

Since the mid-1980s, the *Innovation Systems (IS)* perspective has become dominant in innovation literature. In the Innovation Systems perspective, many components – not just the relative price of the technology – are taken into account to explain the development, diffusion, and implementation of innovations: for instance actors, markets, networks, and institutions. As Bergek (2002) (p.19) states in her thesis:

> "It is the character of such systems that we need to comprehend if we are to understand how an energy system is transformed and how new industries emerge".

This systemic perspective and the interdependency between innovation processes and the institutional context can also be found in the definition of carbon lock-in by Unruh (2000) (p.817):

> "…lock-in occurs through combined interactions between technological systems and governing institutions".

As long as the environmental effects caused by fossil fuels – the so-called external effects – are not integrated in the market price, the relative advantage of renewable energy sources is difficult to turn into an economic advantage. Therefore, the diffusion of renewable energy sources strongly depends on government policies. In this case, the interdependence between the successful diffusion of renewable energy and the institutional context may be of even greater importance than in the case of non-sustainable innovation processes.

In literature, different types of Innovation Systems are discerned where each type focuses on a specific aspect, depending on one's unit of analysis. In the National Innovation Systems approach, it is the country that is the unit of analysis, influencing the technology choice and learning processes (Freeman 1987; Lundvall 1992; Nelson 1992). Then there is the Regional Innovation Systems approach within a country, where cultural variables, such as social networks, are important (Saxenian 1991). The Sectoral Innovation System focuses on the firms that are active in the innovative activities of a sector (Breschi and Malerba 1997).

All of these approaches mainly focus on the analysis of structural elements of the respective Innovation Systems. The structural elements are useful for delineating the system; however, they differ strongly per country or per technology. In addition, if only the structures of different systems are compared and the differences in performance are explained with respect to the differences in structure, less attention is paid to the dynamics of Innovation Systems. This makes the analysis of an Innovation System quite static.

Since the interest of this thesis lies in creating insight into the dynamics of the development and diffusion of renewable energy, another approach is needed that allows a dynamic analysis of the Innovation System.

In this case, the Technological Innovation Systems approach is most suitable since it focuses on a particular technology and it includes factors that are specific to the technology studied (Carlsson and Stankiewicz 1991; Carlsson 1997). The concept of Technological Innovation Systems focuses on all those structural elements (institutions, actors, and networks) that directly influence the development and diffusion of a specific technology. This is a useful delineation if the focus is to identify the characteristics of the specific system associated with an emerging technology, its strength and weaknesses as well as its dynamics (Jacobsson and Johnson 2000). Ever since Carlsson and Stanckiewicz (1991) introduced these concepts, they have been developed into an approach that focuses on the understanding of system dynamics.

Recent authors have focused on the key processes that occur in such a system. In other words, the important factors that influence the development, diffusion, and implementation of that technology have to be identified (Jacobsson and Bergek 2004). These key processes are labelled *Functions of Innovation Systems* (i.e. System Functions)[2]. In this thesis, the System Functions perspective will be applied and evaluated.

In recent years, a small but fast growing body of literature has emerged, stressing the potential of studying System Functions that take place within the Innovation System. Here, a number of System Functions are considered to be important for a Technological Innovation System to develop and, thereby, to increase the success chances of the emerging technology (Johnson 1998; Jacobsson and Johnson 2000; Edquist 2001; Liu and White 2001; Rickne 2001; Jacobsson and Johnson 2002; Hekkert et al. 2006). This approach starts with the assumption that the System Functions are heavily influenced by the different structural elements of the Innovation System. In other words, different regulatory settings and actors may lead to similar effects in terms of System Functions that need to take place. However, not only do the individual System Functions need to take place, they also need to interact with each other as to lead to a build-up of positive cycles that trigger the development, diffusion, and implementation of an emerging technology. By mapping the functional patterns that occur over time, insight into the dynamics on how socio-technical changes occur will be provided.

However, the System Functions approach is not a fully established theoretical framework yet, since different sets of System Functions exist in literature (Edquist and Johnson 1997; Galli and Teubal 1997; Johnson 1998; Liu and White 2001; Jacobsson and Bergek 2004; Hekkert et al. 2006). This makes it both interesting and challenging to empirically differentiate which System Functions are most relevant to understand technological change and how they relate to the structural elements of the Innovation System. In this PhD thesis, one of the aims is to empirically validate the System Functions as identified by Hekkert et al. (2006) for explaining technological change.

Another challenge results from the fact that, until now, the System Functions approach has only been empirically validated by a limited amount of retrospective case studies, primarily using interview data. A drawback that might occur when basing a longitudinal analysis solely on interview data, is the retrospective bias that may occur if processes or events that happened in the past need to be recalled. To overcome these methodological limitations, a more reliable and systematic research method is needed. In the influential Minnesota Innovation Research Programme (MIRP), a different methodological approach is used to study the dynamics of innovation processes. This longitudinal research method has proven to be quite powerful in creating insights into the dynamics of innovation (Van de Ven 1990; Van de Ven et al. 1999). This method is based on event analysis, and is called *process study* (Van de Ven et al. 1999; Poole et al. 2000). The data retrieved by process studies include quantitative measurements of key variables, and/or detailed descriptions of events that contribute to the change and development of the processes studied. Based on the events, a timeline is constructed and illustrated by a narrative, where the circumstances that cause certain twists and turns are identified (Poole et al. 2000). In the studies carried out by Van de Ven and colleagues, the level of analysis lies on a particular innovation project. In this PhD thesis, the process study approach will be adapted and applied to the Innovation System level.

Furthermore, this event based longitudinal process study is applied to reconstruct the technological trajectories of four renewable energy technologies. The technologies are four biomass technology case studies:

1. Biomass digestion in the Netherlands, 1980-2004
2. Biomass digestion in Germany (1990-2006) compared to biomass digestion in the Netherlands (1980-2004)
3. Biomass gasification in the Netherlands, 1980-2004
4. Biomass combustion compared to co-firing and biomass gasification in the Netherlands, 1980-2004

The choice for biomass energy conversion technologies results from the gap between the high theoretical expectations of biomass to contribute to a renewable energy supply worldwide, and the actual practice which shows that biomass based energy technologies develop but slowly. This makes it particularly interesting and challenging to identify the underlying processes that trigger or hamper the development, diffusion, and implementation of these biomass technologies.

This thesis has two goals. First, it aims to create more insight into the relation between the way in which System Functions are being fulfilled and how they contribute to the development and diffusion of renewable energy technologies. Second, it aims to contribute to the further development of the System Functions framework, by testing the set of System Functions on completeness and redundancies, and by developing new methodologies.

1.2 Research Questions

The focus and aim of this thesis as identified above, can be summarised into the following research questions:

RQ 1: How can the process study approach be applied in order to analyse System Functions and the dynamics of Technological Innovation Systems?
RQ 2: How suitable is the set of System Functions to describe and analyse the dynamics of the TIS?
RQ 3: What do functional patterns tell us about the dynamics of Biomass Innovation Systems?

RQ 4: What can we learn from the approach applied and findings obtained, in terms of options to accelerate the diffusion of biomass in particular and renewable energy in general?

1.3 Thesis Outline

Chapter 2 (Theory) provides an overview of approaches often used in studies devoted to understanding socio-technical change, such as Transition Management, Multi-Level Perspective, and Strategic Niche Management. Innovation Systems and System Functions are provided.

In Chapter 3 (Methodology), the process study used to retract events from literature is described in detail. Chapter 4 provides an overview of technical details and processes of the technologies examined. The results section is divided into five chapters, where chapter 5-8 contain the results obtained from the empirical data and chapter 9 provides methodological results. Chapters 5-7 were previously written in paper format; each contains a case specific research question. The combined answers to those case specific questions also provide answers to the main research questions RQ1 and RQ3 (see above).

For the biomass digestion case in the Netherlands (Chapter 5), focus is to provide an explanation for the low diffusion of biomass digestion technology in the Netherlands by means of applying the System Functions approach. Furthermore, an event analysis is performed.

In Chapter 6, the same analysis is performed for biomass digestion technology in Germany, and the findings from that case are compared to those of the Netherlands. The German case has been chosen, as it is a success story with respect to the diffusion of biomass digestion plants in comparison to the Netherlands, thus more insight into the explanation of the difference of diffusion is expected to be gained.

The evolution of biomass gasification in the Netherlands is described in Chapter 7, as the expectations around this technology were high and a quick breakthrough of the technology was expected.

Chapter 8 is somewhat different compared to the other case studies. The previous case studies focused on the evolution of one technology whereas, in this chapter, three technologies are compared, i.e. biomass combustion compared to co-firing and biomass gasification in the Netherlands. This setup was chosen to obtain insight into the technology competition within the Biomass Electricity Innovation System.

Chapter 9 provides answers to methodological matters, such as the testing of the System Functions and the process study approach.

Finally, in chapter 10, the findings of the individual case studies are compared and lessons are drawn, as to answer all of the research questions.

Notes

1 Fossil fuels make up approximately a percentage of 86.7% of the world's total energy supply: 34.4% Oil, 21.2% Gas, 24.4% Coal, 6.5% Nuclear, and 13.3% Renewables (IEA 2000b; IEA 2004)

2 A note for social scientists: the term 'function' should not be associated with functionalism in social science. In this case, the term function should be read from an engineering perspective; systems and devices have functions that they are supposed to serve. For example, the function of a boiler is to provide hot water, the function of a car is to provide mobility.

2 Theory

The long-term process of changing the current energy system into a more renewable energy system can be seen as a long-term process of technological change. The term 'transition' is often used while describing such a process of change. More specifically, a large diffusion of renewable energy is often considered synonymous with technological transition (TT).

This chapter starts with a literature overview of several theoretical frameworks used to study technological change and transitions. In section 2.3 and 2.4, the theoretical concepts tested and applied in this thesis, will be described.

2.1 Technological Transitions

The term technological transition seems to have become the most widely accepted concept by scholars interested in linking social and technical dimensions of change. Rotmans et al. (2001) (p. 1258) describe the generic term 'transitions' as "transformation processes in which society changes in a fundamental way over one or more generations". The concept of transition stems from biology and population dynamics, where a demographic transition is successful when birth and death rates stabilise after a period of growth (Rotmans et al. 2001). Transitions are not uniform, nor are such processes deterministic: there are large differences in the scale of change and the period over which it occurs. Transitions involve a range of possible development paths, the direction, scale, and speed of which can be influenced but never entirely controlled by government policy (Rotmans et al. 2001). A transition can be seen as a spiral that reinforces itself, with multiple causalities and co-evolutions caused by independent developments. Since transitions are multi-dimensional with different dynamic layers, several developments must come together in several domains for a transition to occur (Rotmans et al. 2001). However, those changes will not occur simultaneously. It will be a gradual, continuous process taking at least one generation. This long duration results from the stability and inertia of the established equilibrium, where for a transition to occur, a fundamental change of assumptions and the introduction of new practices and rules are necessary (Rotmans et al. 2001). This recognition corresponds with the concept of lock-in by Unruh (2000) (p.818), who states that:

> "once locked-in, [technology and institutions] are difficult to displace; they can lock-out alternative technologies for extended periods…"

As the focus of this thesis lies on the development, diffusion, and implementation of new technologies, the next paragraph will further describe technological transitions. Geels (2002) (p. 1258) states that technological transitions "consist of a change from one socio-technical configuration to another, involving the substitution of a technology as well as changes in elements such as user practices, regulation, industrial networks, infrastructure, and symbolic meaning". As the elements in a socio-technical configuration are linked and aligned with each other, such reconfiguration processes do not occur easily (Geels 2002). Technology plays an important role in fulfilling societal functions, yet its functioning depends upon its relationship with other elements. Technologies realise functionalities in concrete user contexts, which are made up of users, their competencies, preferences, cultural values, and interpretations. Technologies also need to be produced, distributed, and 'tuned' to an existing user context (Geels et al. 2004). However, new technologies have a hard time breaking through, since regulations, infrastructure, user practices, and maintenance networks are aligned with the existing technology. Thus, they often face a mismatch with the established socio-institutional framework, as described by Rosenberg (1976) (p. 195):

> "when new technologies emerge they are still inefficient, crude, badly adapted and cannot immediately compete on the market with established technologies".

Before elaborating on how to overcome mismatches and on new technologies to become successful, provided below is an overview of the different phases of a transition.

Rotmans et al. (2000) distinguish four different transition phases. By dividing the transition process into phases, the analysis of the occurrence of transitions is more manageable. However, it does not provide any insight into the dynamics of the transition process. The four phases are described below, based on the description of Van Lente et al. (2003).

(1) A *predevelopment or exploration phase* consists of a multitude of search processes within laboratories and universities and between stakeholders, which leads to new options and varieties. These search processes are not linear and can be labelled 'creative destruction' as, incessantly, something new is created, destroying something old (Schumpeter 1943). This process is necessary for new technologies to break through, as they build on earlier inventions and on each other, and they refer to each other. Innovation processes are related, as the technical and the social are interrelated; problems and solutions co-evolve within this process. Finally, the exploration phase is marked by a growing awareness of possible new encompassing societal goals, such as a sustainable energy system.

(2) In the *take-off phase*, the process of change starts to occur as the state of the system begins to shift. In the case of transitions and system innovations, the importance does not lie in the succession of technologies but in a system change. These system changes often involve changes in technological paradigms (Dosi 1982), such as the way of thinking or designing. Within this system change, competition between trajectories occurs, which can be compared to the life cycles of innovations, where new technologies compete with both established and new technologies until a dominant design emerges (Tushman and Rosenkopf 1992; Utterback 1994a). However, until then, what dominates is the established system that has gained advantage on the basis of its history rather than on its technical superiority. This lock-in situation cannot be undone without great effort and expenses, due to the fact that the established system profits from sunk investments. One way for an innovation to break through is to create protected spaces or niches in which the new technology can be introduced and where actors can experiment with the new technology (Kemp et al. 1998). Again, before the breakthrough occurs, expectations of what others will do dominate the

decisions of the actors, such as avoiding to take the same direction as others or to miss 'jumping on the bandwagon' (Van Lente and Rip 1998). Finally, it is assumed that there are two crucial types of activities that should be fulfilled during the take-off phase: the new system should get a critical mass of stakeholders, and promising niches should be identified or created.

(3) A *breakthrough* phase, also called entrenchment or embedding phase, is characterised by visible structural changes that take place through an accumulation of socio-cultural, economic, ecological, and institutional changes reacting to each other. Since the various socio-technical developments of a new system have become interconnected with and reinforce each other, the system may become irreversible: there is no way back. In the case of a considerable number of products in this phase, a shakeout will occur.

(4) A *stabilisation* phase is reached when the speed of social change decreases and a new dynamic equilibrium is reached. The new systems have now become so established in current routines, infrastructure, and legal frameworks that they have become an established system in and of themselves. They can only be undone at considerable costs and effort. However, at a certain point, new routes will be explored all over again and the system might become unstable when a new technological system arises and takes over, just like in the exploration phase. A new life cycle will then take off.

Since our interest lies in the development of emerging technologies, only phases 1 and 2, and to a certain extent phase 3, will be considered, since the technologies analysed are not yet entrenched in the system.

Transitions can be studied at different aggregation levels, to track developments over the course of time and compare them with each other (i.e. historical case studies of energy sector, technologies, etc). Rotmans et al (2001) distinguish three aggregation levels:

- Micro – individuals or individual actors, e.g. firms, environmental movements
- Meso – networks, communities, and organisations
- Macro – conglomerates of institutions and organisations, e.g. a nation or federation of states

This division corresponds – more or less – to the classification that describes changes in socio-technical systems, namely niches, regimes, and socio-technical landscapes (Kemp et al. 1998; Rotmans et al. 2001). This so-called 'Multi Level Perspective' (MLP) is dominant in studies that focus on understanding technological transitions, since it studies the interactions between *niche-innovations* and existing *regimes*, situated in a broader environment (Verbong and Geels In press).

The macro-level is defined as the *social-technical landscape,* where technological trajectories are situated. It contains a set of heterogeneous factors, such as oil prices, economic growth, wars, broad political coalitions, culture, and environmental problems, and it acts as external structure or context for interactions of actors. A characteristic of this level is that it is slow in its response to trends and developments. Furthermore, it influences regime dynamics and niches (Rotmans et al. 2001; Geels 2002; Verbong and Geels In press).

The *socio-technical regime* forms the meso-level, which refers to rules enabling and constraining activities within communities (Geels 2002). The regime consists of three interlinked dimensions, according to Verbong and Geels: a) a network of actors and social groups, b) formal normative and cognitive rules, and c) material and technical elements (Verbong and Geels In press).

Niches form the micro level; the role of niches is further developed in the Strategic Niche Management (SNM) approach. This approach aims to understand how the process of technological development comes about, where it can be used as a research model to analyse historical case studies and as a policy tool to formulate suggestions for policy makers (Raven 2005). Niches are the places where novelties emerge, since they act as 'incubation rooms', shielding new technologies from the mainstream market selection. As new technologies have a low price/performance ratio, protection is needed and can be provided by small networks of actors who are willing to invest in the development of new technologies. Within the niches, the most important processes are i) the building of social networks, ii) learning processes, and iii) the articulation of expectations to guide learning processes. As these processes can reinforce each other in the form of positive feedbacks, an internal momentum is created in the niche (Geels and Raven submitted; Raven 2005). The internal momentum in the niche is important, but it is not sufficient for a breakthrough (Geels and Raven). For a breakthrough to occur, it is important that developments at all three levels (landscape, regime, and niche) are linked up, reinforcing each other (Rotmans et al. 2001; Geels 2002). In addition, changes at the level of regime and landscape need to occur, offering a 'window of opportunity' for the new technology to break out of the niche. However, this process does not occur at once, it needs to build up gradually by following trajectories of niche-accumulation, i.e. by experimentation, learning processes, adjustments, and reconfigurations in various niches (Geels 2002).

To summarise, the key point of the Multi Level Perspective is that transitions and system innovations occur through the interplay between dynamics at multiple levels. These are no processes of simple 'cause' and 'effect', but of 'circular causality' where system transformations come about when these processes link up and reinforce each other (Geels and Raven submitted). Since the breakthrough of a new technology is expected to come from an accumulation of niches, the Strategic Niche Management approach is applied to further investigate the role of niches (Raven 2005).

However, in the Multi Level Perspective, only niche internal processes are specified. Interactions between niche and regime are claimed to be important, yet the interactions are not specified in terms of processes. Thus, what is missing in the Multi Level Perspective approach is, first, a theory on the successful growth of a niche for it to become part of the regime. Second, what misses is insight into the key processes that influence the successful breakthrough of a niche into the regime. Finally, what we need is a theory that includes the interaction process between an innovation and the surrounding networks and institutions.

In this case, the Innovation System framework might provide such a theory.

2.2 Innovation Systems (IS)

The processes through which technological innovations emerge are extremely complex and related to the emergence and diffusion of knowledge elements (i.e. scientific and technological possibilities), as well as the 'translation' of these elements into new products, services, and production processes (Edquist 1997; Lundvall et al. 2002). However, this translation does not follow a linear path from basic research to applied research and, subsequently, to the development and implementation of new processes and new products (Edquist 1997; Lundvall et al. 2002). Instead, it is characterised by complicated feedback mechanisms and mutual interactions involving science, technology, learning, production, policy, and demand (Edquist 1997; Lundvall et al. 2002; Smits and Kuhlmann 2004). Innovation processes occur over time and are influenced by many factors. Because of this complexity, "firms never innovate in isolation" (Edquist 1997; Edquist 2001). In the pursuit of this complexity, they interact with other organisations to gain, develop, and exchange various kinds of knowledge, information, and other resources. These organisations might be other firms (suppliers, customers, competitors) but also universities, research institutes, investment banks, schools, government ministries etc. Through their innovative activities firms often establish relations with each other and other kinds of organisations. Therefore, innovating firms should not be regarded as isolated, individual decision making units (Edquist 1997; Edquist 2001). To put it differently, firms operate within a context. This context is labelled an Innovation System.

The underlying idea is that innovations are often developed within systems formed by actors and organisations, which all contribute to innovations in different and interactive ways. The relationship between the actors and organisations and the influencing institutions form the Innovation System (Carlsson et al. 2002). Each author defines Innovation Systems differently, depending on the element(s) he/she considers most important and on the level of analysis he/she is most interested in.

Freeman introduced the concept of Innovation Systems in 1987. It was then further developed by Lundvall and Nelson into National Innovation Systems (NIS) (Freeman 1987). Freeman (1987) stresses the importance of institutions[1]. He defines the Innovation System as "the network of institutions in the public and private sectors, whose activities and interactions initiate, import, modify, and diffuse new technologies" (Freeman 1987).

Lundvall (1992) (p. 2) emphasises that learning is the central activity in Innovation Systems, where "learning is a social activity, which involves the interaction between people" (Lundvall 1992). This shows that the Innovation System is a social and dynamic system, characterised by positive feedback and reproduction (Lundvall 1992). The processes of learning and innovation can be promoted by the elements of the Innovation System that reinforce each other, or conversely, that block such processes when they combine into constellations that are unfavourable (Lundvall 1992). Furthermore, it is very important that the knowledge of individuals or collective agents is reproduced and exchanged (Lundvall 1992) (p. 1).

The notion of NIS places a major emphasis on the role of nation states, where the geographical boundaries of the Innovation System are fixed. Within these boundaries, country-specific factors influencing the innovative capabilities of national firms are studied (Edquist 1997). By using national boundaries, actors sharing a common culture, history, language, social and political institutions are identified (Edquist 1997). Thus, the focus of NIS is to identify the importance of interactions among many agents and the way in which they support learning which promotes innovation (Senker et al. 1998). However, in an internationalised and globalised world, the question arises whether national boundaries are still relevant and whether they exist at all. Furthermore, the questions arise whether NIS differ by industrial sector and whether firms can be considered to be strictly national (Senker et al. 1998). However, as there is no focus on specific industries or technologies within the NIS, other approaches will have to be used to provide answers.

One way is to apply the concept of Sectoral Innovation Systems (SIS), defined by Breschi and Malerba (1997) (p.131) as:

> "…the system (group) of firms developing and making a sector's products and generating and utilising a sector's technologies…" (Breschi and Malerba 1997)

The focus of SIS lies on agents and firms, putting much emphasis on non-market interactions and on the processes of transformation of the system (Malerba 2002). Furthermore, it focuses on competitive relationships among firms by explicitly considering the role of selection environment, where the main concern lies on the overall dynamics in the population of firms active in a sector (Breschi and Malerba 1997). The boundaries for the SIS emerge from the specific conditions of each sector, by focusing on the sources of knowledge and on the role played by geographical space in the processes of knowledge transmission (Breschi and Malerba 1997).

However, as the major interest of this thesis is to understand and analyse technological change, the appropriate Innovation System in this case is the Technological Innovation System (TIS). This approach can be summarised in the concept of technological systems[2]. This concept enables to study the characteristics of the system associated with a specific emerging technology, to analyse its strengths and weaknesses as well as its dynamics, and to compare it with the system of an incumbent technology system (Jacobsson and Johnson 2000). The regional or local dimension is included in this approach as well (Carlsson and Jacobsson 1997). However, if the main concern is to understand technological change, the dynamics of the Innovation System need to be identified. On the national level, the dynamics are difficult to map, since the complexity of the National Innovation System is considerable, due to the vast amount of actors, network relations, and institutions (Hekkert et al. 2006). As a result, many authors studying and comparing National Innovation Systems, focus on its current structure, presenting a static description of the structure without focusing on mapping the dynamics (Hekkert et al. 2006). Since the focus of the Technological Innovation System lies on a specific technology, it reduces the complexity of the system. This reduced complexity enables the mapping of the dynamics.

2.3 Technological Innovation Systems (TIS)

Technological Innovation Systems consist of networks of firms, R&D infrastructure, educational institutions, and policy-making bodies that exclude artefacts (Carlsson 1997). They are defined by Carlsson and Stanckiewicz (1991) (p. 94) as:

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

In comparison to sectoral systems where the focus lies on "firms that are active in the innovative activities of a sector" (Breschi and Malerba 1997) (p. 131), the Technological Innovation System approach focuses on a specific technology (Carlsson 1997; Carlsson et al. 2002). Contrast to

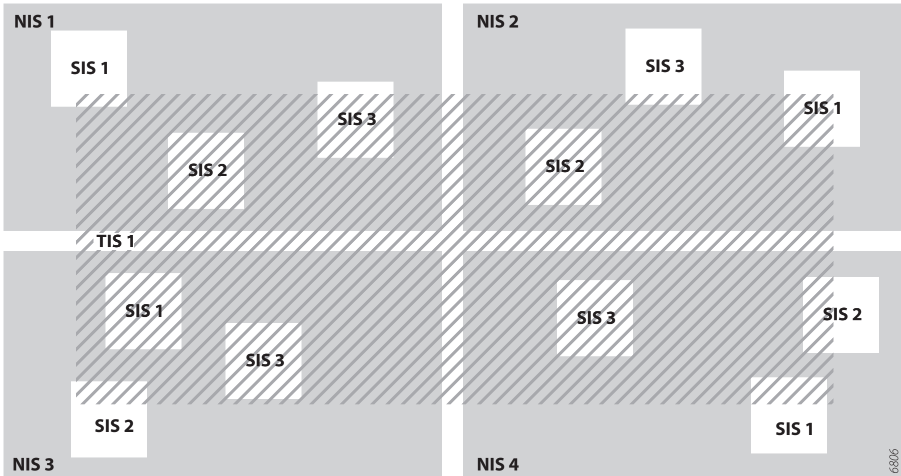

Figure 2.1 Potential overlap of Technological Innovation System within National and Sectoral Innovation Systems

National Innovation Systems, there are several technological systems in each country where the national borders do not necessarily form the boundaries of the system (Carlsson 1997; Carlsson et al. 2002). They can be, but are not necessarily restricted to one industrial branch. Carlsson and Stankiewicz (1991) (p.111) state that:

> "…the Nation-state constitutes a natural boundary of many technological systems. Sometimes, however, it may make sense to talk about a regional or local technological system… in yet other cases, the technological systems are international, even global. Where the boundaries are drawn depends on the circumstances, e.g. the technological and market requirements, the capabilities of various agents, the degree of interdependence among agents, etc".

Thus, Technological Innovation Systems can be national, regional, and international. Figure 2.1 schematically represents how the Technological Innovation System relates to the geographical and sectoral dimension of, respectively, the National Innovation System and the Sectoral Innovation System approach. It shows that the Technological Innovation System overlaps with parts of various National Innovation Systems and Sectoral Innovation Systems, which, in turn, are embedded in the National Innovation Systems. Thus, by taking a specific technology as a starting point, the Technological Innovation System approach cuts through both the geographical and the sectoral dimensions (Hekkert et al. 2006).

One of the most significant features that differentiates this approach from other Innovation System approaches is that it often analysed an emerging system rather than a mature system (Carlsson 1997). The characteristics of the newly emerging systems are different from those of mature systems. The configuration of actors and institutions change over time as the system still develops (Carlsson 1997). Since the systems evolve over time, the need for longitudinal studies is justified (Carlsson 1997; Carlsson et al. 2002).

Earlier on, it was explained that the focus on the Technological Innovation System has several advantages (it is more specific and, thus, better suited for a dynamic analysis) over a National Innovation System focus, since the typical National Innovation Systems analysis is quite static. In order to achieve the desired *changes* in a system, it is important to understand what *happens* in the system and to focus on the factors that influence system dynamics; in our case the factors that determine the development, diffusion, and implementation of a technology. Recently, a new approach was developed that deals specifically with these Innovation System dynamics. The framework is labelled Functions of Innovation Systems (Johnson 1998; Jacobsson and Johnson 2000; Liu and White 2001; Rickne 2001). The following paragraph elaborates on this concept and on how it is applied in this thesis.

2.4 Functions of Innovation Systems

Edquist (2001) states that the determining factors (economic, social, political, and organisational etc.) that influence the development, diffusion, and use of innovations, can be traced by identifying all activities that take place within Innovation Systems. However, it is not feasible to map them all, therefore, only the most relevant activities are included, i.e. those that influence the goal of the Innovation System. The activities that contribute to the goal of the Innovation Systems are called Functions of Innovation Systems or System Functions (Hekkert et al. 2006). Jacobsson and Johnson (1998, 2000, 2002) developed the concept of System Functions and defined it as “a contribution of a component or a set of components to a system’s performance” (Bergek 2002 p. 21). They argue that a Technological Innovation System, “may be described and analysed in terms of its ‘functional pattern’, i.e. by the way these functions have been served” (Bergek 2002 p. 24). The System Functions are “related to the character of, and the interaction between, the components of an Innovation System, i.e. actors (e.g. firms and other organisations), networks, and institutions, which may be specific to one Innovation System or ‘shared’ between a number of different systems” (Jacobsson and Johnson 2000 (p. 3); Edquist 2001 (p. 9)). To understand how a technology is developed, diffused, and implemented, the functional pattern of the related Technological Innovation System needs to be analysed over time. As emerging technologies still reside in development stages, diffusion patterns are missing and cannot be used for evaluation. Thus, as a first proxy, we assume that the more (and the better) System Functions are served, the better the performance of the Technological Innovation System will be, thus the better the development, diffusion, and implementation of innovations will be (Edquist 2001)[3].

As mentioned earlier, the concept of System Functions makes it possible to study the dynamics of Innovation Systems by mapping the functional patterns. This is done by studying the dynamics of each System Function separately, plus the interdependencies between the System Functions. This provides a structure to describe the innovation process and it contributes to the understanding of how Innovation Systems emerge and change and how they could be stimulated appropriately for the development, diffusion, and implementation of renewable energies (Johnson 1998).

In recent literature, several lists of System Functions have already been suggested, for instance by Jacobsson and Johnson (1998; 2000; 2002), Rickne (2001), and Liu and White (2001). However, there has been no consensus or empirical proof yet as to which set of System Functions performs best in describing the dynamics of a Technological Innovation System. In Hekkert et al. (2006), the various existing sets of System Functions have been discussed and one set of System Functions is proposed. This set of System Functions will be used to structure the empirical work in this thesis. In the following paragraph, the different lists of System Functions will be discussed. Subsequently, the individual System Functions will be described, based on Hekkert et al. (2006).

2.4.1 System Functions in Literature

The most basic System Function mentioned in many Innovation System studies, is the activity of 'learning' or 'interactive learning'. This activity lies at the core of the Innovation System approach (Lundvall 1992). Edquist and Johnson (1997) mention three functions of institutions in innovation systems: institutions reduce uncertainty by providing information, they manage conflicts and cooperation, and they provide incentives for innovation.

McKelvey (1997) discerns three different functions of Innovation Systems as she explicitly defines the Innovation System according to evolutionary theory: (i) retention and transmission of information, (ii) generation of novelty leading to diversity, and (iii) selection among alternatives. The necessary activities in the Innovation System correspond exactly with the main principles of evolutionary economics: variety, selection, and retention. The importance of networking is particularly stressed (McKelvey 1997).

In Galli and Teubal (1997), specific attention is paid to National Innovation System functions and linkages; in their study, evolution and transition of Innovation Systems are discussed. They state that it is important to discern between organisations and functions, since organisations can have multiple roles. Furthermore, they discern between hard and soft functions. Hard functions require hard organisations (i.e. performing R&D), while soft functions may be operated by soft institutions (not performing R&D, for instance regulatory entities) and involve catalytic and interface roles only (Galli and Teubal 1997). Hard functions are: (i) R&D activities (public) and (ii) the supply of scientific and technical services to third parties (business sector and public administration). Soft functions include: (i) diffusion of information, knowledge, and technology, (ii) policy making, (iii) design and implementation of institutions concerning patents, laws, standards, etc., (iv) diffusion of scientific culture, and (v) professional coordination. Even though Galli and Teubal (1997) stress the importance of discerning between organisations and functions, the functions are a relatively straight extrapolation of the classic modules present in the Innovation System. Functions at a more abstract level, which can be fulfilled by separate parts of the innovation system (like the functions of McKelvey (1997)), are not present in their overview.

This type of direct extrapolation of system modules to functions is also performed by Liu and White (2001) (p. 1092), who address what they call a fundamental weakness of National Innovation System research, namely the lack of system-level explanatory factors. Therefore, they focus on the following five activities in the systems (Liu and White 2001):

i. Research (basic, development, engineering)
ii. Implementation (manufacturing)
iii. End-use (customers of the product or process output)
iv. Linkage (bringing together complementary knowledge)
v. Education

Johnson (1998) gives an overview of the Innovation System literature to find out whether there is a shared understanding of which functions ought to be served in Innovation Systems. Based on this literature overview, she identifies eight system functions:

i. Supply incentives for companies to engage in innovative work
ii. Supply resources (capital and competence)
iii. Guide the direction of search (influence the direction in which actors utilize resources)
iv. Recognise the potential of growth (identifying technological possibilities and economic viability)
v. Facilitate the exchange of information and knowledge
vi. Stimulate/create markets
vii. Reduce social uncertainty (i.e. uncertainty about how others will act and react)
viii. Counteract the resistance to change that may arise in society when an innovation is introduced (provide legitimacy for the innovation)

This set of functions differs from the previous sets, as the functions are formulated in an active sense. In this case, the functions are almost synonymous with a set of policy recommendations. In fact, this set of functions seems to take off from the starting point that the typical modules in Innovation Systems are present, but that there are key activities that need to be performed before these modules function well. Note the difference between Liu and White's 'Research' and Galli and Teubal's 'R&D' on one hand, and the first three functions of Johnson (1998) on the other hand. The latter indicates what system activities need to take place in order to enable effective and efficient research.

In the empirical work following this work of Johnson (1998), the list of eight functions is reduced to five functions (Jacobsson et al. 2004):

i. Create new knowledge
ii. Guide the direction of search processes
iii. Supply resources
iv. Facilitate the creation of positive external economies (in the form of an exchange of information, knowledge, and visions)
v. Facilitate the formation of markets

In these empirical studies, the approach has proven to be suitable to describe and (begin to) explain the transformation of specific transitions in Technological Innovation Systems. The construction of this set of functions and its use for empirical studies is in line with the recommendations given by Lundvall (1992), who states that making the system of innovation concept more dynamic is a major step in the direction of future research. Furthermore, he advises to focus on all aspects of competence building instead of having a narrow focus on science and science-based activities. This is exactly what the utilisation of this set of functions accomplishes.

There are three reasons for adopting the System Functions approach. First, the perspective makes it more feasible to perform a comparison in terms of performance, throughout the Innovation System with different institutional setups. Second, the perspective permits a more systematic method of mapping determinants of innovation; this increases the analytical power of the Innovation System approach, especially when performing a longitudinal analysis:

> “The external dynamics of an innovation may be studied by drawing maps of functional patterns over time. The internal dynamics are created by the interaction of functions, which make it possible for cumulative and circular causation to appear. By studying feedback loops between functions, it is, thus, possible to get a picture of the internal dynamics of the system (Bergek 2002) (p.24).”

Third, the System Functions perspective has the potential to deliver a clear set of policy targets as well as instruments to meet these targets:

> “System performance may be evaluated in terms of the ‘functionality’ of a particular Innovation System, i.e. in terms of how well the functions are served within the system (Bergek 2002) (p.24). ”

The meaning of ‘well served’ for capital goods industry development is expected to differ depending on what particular stage of evolution an industry is in (Tushman and Nadler 1978; Utterback 1994b; Bergek 2002).

Based on the different categories of functions and several empirical studies at Utrecht University (Hekkert et al. 2006; Negro et al. 2007; Negro et al. In Press), the following set of System Functions is proposed that will be applied to map the key activities in Innovation Systems, and to describe and explain shifts in Technological Innovation Systems[4].

2.4.2 Definitions of System Functions

Function 1. Entrepreneurial Activities
The existence of entrepreneurs in the Innovation System is of prime importance. Without entrepreneurs, innovation would not take place and the Innovation System would simply not exist. Thus, the entrepreneur is essential for a well-performing system. In this thesis, the concept of ‘entrepreneur’ is broader than the one used in economic literature where the entrepreneur refers to a private actor. Although entrepreneurs can often be found in the private sector, from an innovation systems perspective, public actors or combinations of public and private actors may act as entrepreneurs as well. The role of the entrepreneur is to turn the potential of new knowledge development, networks, and markets into concrete actions in order to generate and take advantage of business opportunities. Entrepreneurs can be new entrants who recognise such opportunities in new markets, or they can be incumbent companies who diversify their business to take advantage of new developments.

Function 2. Knowledge Development (learning)
Mechanisms of learning lie at the heart of any innovation process. According to Lundvall (1992) (p. 1), “the most fundamental resource in modern economy is knowledge and, accordingly, the most important process is learning”. New knowledge has to be developed if solutions to the identified problems are called for, i.e. the development of a new technology, in which the development of scientific and technological knowledge is crucial. Possible sources of new knowledge are R&D, search and experimentation, learning-by-doing/using, and imitation, where

the combination of old and new knowledge in innovative ways and the reuse of old knowledge by imitation are included.

Function 3. Knowledge Diffusion through Networks
The network determines the structure of the Innovation System; it can be considered an intermediate form of organisation between organisations and markets. According to Carlsson and Stankiewicz (1991), its essential characteristic is the exchange of information. This is important in a strict R&D setting, but especially in a heterogeneous context where researchers meet government representatives, competitors, and the market. Networks allow policy decisions (e.g. standards, long-term targets) to be based on the latest technological insights. The diffusion through networks of information on, for example, changing norms and values, can lead to changing R&D agendas.

Function 4. Guidance of the Search
Since natural resources are limited, it is important that, in the case of various different technological options, specific foci are chosen for further investments. Without this selection, there will be insufficient resources left for the options chosen. The function can be fulfilled by a variety of system components such as industry, government, and/or market. As a System Function, Guidance of the Search refers to those activities within the Innovation System that can positively affect the visibility and clarity of specific wants among technology users. An example is the government announcement to aim for a certain percentage of renewable energy in a future year. This event grants a certain degree of legitimacy to the development of sustainable energy technologies and it stimulates the allocation of resources for this development.

An important, though elusive, class of phenomena here relates to expectations (see the work of van Lente (1998; 2000)). Often, actors are initially driven by little more than a hunch. Vague ideas are often tried out and their success (and failure) can be communicated to other actors, thereby reducing the (perceived) degree of uncertainty. Occasionally, under the influence of 'success stories', expectations of a specific topic converge and generate a momentum for change into a specific direction.

Function 5. Market Formation
New technologies often encounter difficulties to compete with embedded technologies. Therefore, it is important to create protected spaces for new technologies. One possibility is the formation of temporary niche markets for specific applications of a technology (Schot et al. 1994). Another possibility is to create a temporary competitive advantage by favourable tax regimes or minimal consumption quotas.

Function 6. Resource Mobilisation
Resources, both financial and human capital, are necessary as a basic input to all of the activities within the Innovation System. Specifically for biomass technologies, the abundant availability of the biomass resource itself is an underlying factor determining the success or failure of a project. This function is difficult to analyse by specific indicators, since the information about whether resources are sufficiently available or not, are always based on the perception of the actors of the field. Actors of the emerging system will always complain that insufficient resources are

available; actors of the incumbent system, on the other hand, will insist that sufficient resources are provided.

Function 7: Advocacy Coalitions (Creation of Legitimacy/Counteract Resistance to Change)
In order to develop well, a new technology has to become part of an incumbent regime, or it even has to overthrow it. Parties with vested interests will often oppose this force of 'creative destruction'. In that case, advocacy coalitions can function as a catalyst; they put a new technology on the agenda (function 3), lobby for resources (function 6) and favourable tax regimes (function 5) and, by doing so, create legitimacy for a new 'technological trajectory' (Sabatier 1988; Sabatier and Jenkinssmith 1988; Sabatier 1998). If successful, advocacy coalitions grow both in size and in influence and may become powerful enough to ignite the spirit of creative destruction.

As stated before, our framework starts with the proposition that all of the seven System Functions are important to reach a good system performance. However, if one had to rank the different System Functions, one might state that functions two to seven support function one; they create the correct entrepreneurial climate for entrepreneurial activities to blossom. However, it is the *combination* of all of the System Functions that leads to system performance, not merely entrepreneurial activities.

2.4.3 Interactions and Momentum of System Functions

The System Functions are not independent but interact with and influence each other. The fulfilment of certain System Functions can affect other System Functions. For instance, a certain amount of knowledge creation (F2) is necessary to create expectations (F4) of the new technology, which may then lead to legitimacy (F7). It is expected that the System Functions will interact with each other in multiple ways, either positively or negatively. The nature of the interactions (positive or negative) will influence the performance of the system. Positive System Function fulfilment can lead to positive (virtuous) cycles of processes that strengthen each other and lead to the build-up of momentum, creating a process of creative destruction within the incumbent system (Jacobsson and Bergek 2004). Given the interdependency of the System Functions, one can even say that a well-developing Technological Innovation System is characterised by one or more *virtuous cycles*. A system in decline is characterised by one or more *vicious cycles*, where the System Functions interact and reinforce each other in a negative way. In order to provide insight into the process of momentum build-up, empirical research should focus on identifying and analysing these cycles.

Figure 2.2 schematically shows some examples of probable virtuous cycles in the field of sustainable technology development. One cycle may start with System Function 4: Guidance of the Search. In this case, societal problems may be identified and government goals may be set to limit environmental damage. These goals may legitimise the mobilisation of resources to finance R&D projects in search of solutions (F6), which in turn, may lead to knowledge development (F2) and increased expectations of technological options (F4). Another virtuous cycle that may be expected to occur starts with System Function 1: Entrepreneurial Activities, as entrepreneurs lobby for better economic conditions to enable further technology development (F7). They may either lobby for more resources (F6) to perform R&D (F2), which may lead to higher expectations (F4), or they may lobby for market formation (F5), as a level playing field is quite often not present . If this lobby (F7) leads to the creation of markets (F5), a boost in

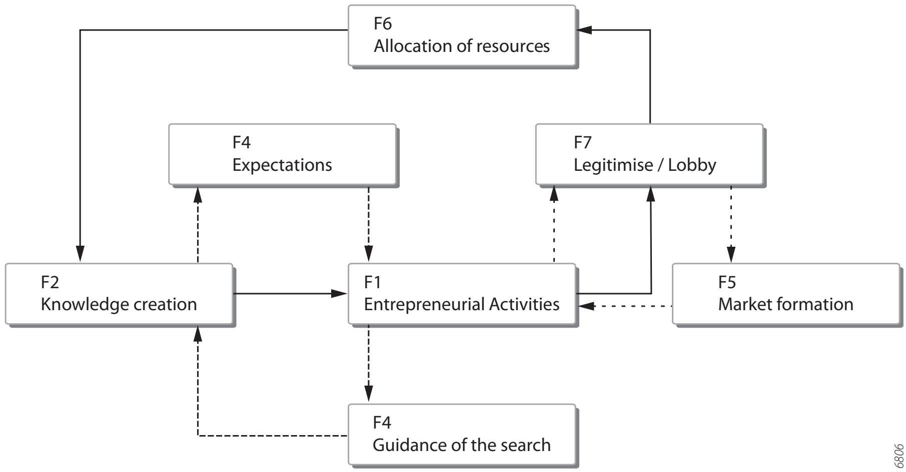

Figure 2.2 A schematic representation of potential virtuous cycles

entrepreneurial activities (F1) may be expected, leading to more knowledge formation (F2), more experimentation (F1), and increased lobbying (F7) for even better conditions, plus high expectations that lead to further research (F4).

These are just examples of how System Functions can interact with each other and lead to such cycles. However, many more combinations are possible and the causality may be very complex indeed.

Vicious cycles are also possible, where a negative function fulfilment leads to reduced activities related to other System Functions, thereby slowing down or even stopping the progress. For example, if the expectations of a technology are high (F4) but the practical results are disappointing, a collective disillusionment in the technology (-F7) may rise, causing no more projects to be set up (-F1). This may reduce the amount of activities for knowledge creation (F2) and availability of resources (-F6). Another possible vicious cycle is the lack of consistent government guidance (-F4), resulting in the absence of a market (-F5), so that no prospect is provided for entrepreneurs to set up projects (-F1). This may, subsequently, lead to less support and lobbying (-F7) for better institutional conditions (-F4) and so forth, until the system eventually collapses.

It is expected that, by applying this approach to structure the longitudinal data of the case studies, several virtuous or vicious cycles will be identified that lead to the explanation of the success or failure of emerging technologies.

In order to monitor the interactions between the System Functions, a dynamic analysis is necessary that takes into account the sequence of all of the relevant processes. An appropriate method is described in literature as 'process approach' or 'sequence analysis' (Abbot 1995; Poole et al. 2000). This process approach conceptualises development and change processes as a sequence of events and explains the outcomes as the result of the order of events (Abbot 1995; Poole et al.

2000; Hekkert et al. 2006). In the next paragraph, a more thorough description of the concrete application to analyse the case studies is provided.

It should be noted that the major goal of this type of analysis is *not* to identify and verify (all) causal relationships in the system. The potential sheer complexity of these feedback mechanisms in system change is a reason for some researchers not to study these patterns. However, if one wishes to understand and influence these processes of change, one can limit the research to identifying virtuous cycles at the level of interacting System Functions, thus analysing the driving forces behind them. Based on this information, certain actions may be defined that increase the chances of reaching the final goal (development of a stable Technological Innovation System).

To summarise, the major goal of using the concept of System Functions is to understand processes of technological change and innovation. By analysing the various System Functions, virtuous and vicious cycles can be identified which enlarge our understanding of the dynamics of a system. By using the process method, the order and sequence of relevant processes is taken into account (Hekkert et al. 2006). Thus, in addition to the Multi Level Perspective and Strategic Niche Management approach, this approach goes one step further by mapping the dynamics around an emerging technology and by identifying the underlying factors that lead to the virtuous cycles that, in the end, may cause the breakthrough of the innovation from the niche level (a Technological Innovation System in phase 2) to the regime level (a Technological Innovation System in phases 3 or 4). As the initial Technological Innovation System may start small (the size of a niche) and grow out to be an incumbent system, insight into the key processes that determine the growth of such a system is a useful addition to the Multi Level Perspective and Strategic Niche Management approach.

Notes

1 In the Innovation System literature, the concept of 'institutions' can play a different role in innovations, and the various authors of IS literature do not mean the same things when using the term institutions (Edquist 1997). On the one hand, institutions are considered 'things that pattern behaviour', such as norms, rules, and laws (e.g. Lundvall), whereas, on the other hand, others consider institutions 'formal structures with an explicit purpose', i.e. what is normally called organisations (e.g. Nelson and Rosenberg) (Edquist 1997). The role of institutions in the sense of R&D laboratories, patent systems, and technical standards is meant to stimulate technical innovation. However, the same institutions can also become barriers that hamper the development and diffusion of a new technical innovation, when they become established and lead a life of their own, they may become unsuitable to stimulate a new technical innovation.

2 The term technological system is, however, confusing. Hughes introduced the notion of Large Technological Systems (LTS), which consists of physical artefacts, organisations, and legislative artefacts (institutions). Carlsson and Stankiewicz exclude physical artefacts in their definition. Thus, from now on, technological systems in the sense of Hughes will be labelled LTS, whereas technological systems in the sense of Carlsson and Stankiewicz are labelled Technological Innovation Systems (TIS).

3 In other projects carried out by PhD students of the Innovation Studies Department at Utrecht University, partly building on this research, the main question is whether or not fulfilment of each function in each of the four transition phases is of equal importance.

4 This list of System Functions has been, to a large extent, developed in agreement with colleagues from Chalmers University (Sweden), to be applied to empirical work both in the Utrecht and the Chalmers group.

3 Methodology

3.1 Introduction

By using the concept of System Functions, the intention is to create deeper insight into the processes of technological change and innovation. In this thesis, this approach will be applied to structure the longitudinal data of four case studies.

One of the assumptions of the System Functions approach is that the acceleration in system development occurs when System Functions interact and lead to virtuous cycles, which may take the fulfilment of the System Functions over a certain threshold[1] (Jacobsson and Johnson 2000). Thus, we need a research approach that takes the order and sequence of all of the relevant processes into account. The so-called *process approach or sequence analysis* (Abbot 1995; Poole et al. 2000; Van de Ven and Poole 2002) is an approach that meets this demand. This approach is described in further detail, based on Poole et al. (2000). The process approach conceptualises development and change processes as sequences of events[2]. By focusing on the stream of events through which the process unfolds, it allows to identify and explore the path the process follows, taking path dependency[3] into account (Poole et al. 2000). By gathering data that indicates how the process unfolds over time, a timeline of events can be constructed that provides significant insights into the development and change process (Poole et al. 2000). A narrative based on these insights can, subsequently, explain the flow of events and the conjunctions of causal forces that move the developing entity through its sequence (Poole et al. 2000). A process study aims to not merely explain one single case; it wishes to provide a general narrative offering a common explanation for a range of cases. In order to achieve this, specific cases have to be subjected to the same analytical framework, in our case the set of System Functions. The differences between the systems, i.e. the amount of events per case, (where cases may have different amounts of events, or where a specific type of event may differ in duration) can be analysed in a systematic way. These differences can then be further described and explained by developing a narrative. The narrative captures the particular causal factors influencing the case, the order in which they occurred and the time span they operated. Narratives provide the 'big picture' that puts individual events and causes into a context, assigning them their significance (Poole et al. 2000). Finally, process study allows us to understand how forces or influences initiated in one event, how they are transmitted or dissipated in subsequent events, and how conjunctions of events produce interactions among causal factors that build momentum or lead to collapse in the development models (Poole et al. 2000). In this way, the process approach creates insight into the underlying mechanisms that determine technological change through time, more so than other approaches that primarily, and often exclusively, focus on the structure of the system (Hekkert et al. 2006).

In studies carried out by Van de Ven and colleagues, events around a specific innovation project are mapped. Due to the focus on the micro level of innovation, detailed information is gathered by means of observing organisational meetings and by studying minutes of meetings and organisational reports (Poole et al. 2000). In this thesis, aim is to map the events that have taken place and that are still taking place within the Technological Innovation System under investigation. This implies a much broader research focus, in contrast to focusing merely on individual innovation processes or agents. The data collection in this case is not so much about following all of the individual agents or innovation projects in the system, it contains the events that are reported at system level relevant to a specific technology.

What does such an approach look like and how is it applied in this thesis? The following paragraph provides a stepwise description.

3.2 Process Analysis as Mapping Method

The procedure described below, comprising eight steps, has been followed throughout this thesis for all of the four case studies.

1. **Literature search:** The first step is to carry out a thorough literature search of Dutch and German journals, newspapers, periodicals, reports, websites, and Lexus Nexus[4] about renewable energy from 1980 until 2004 (in the case of Germany from 1990 until 2005, due to restricted data accessibility). Each event related to the development, diffusion, or implementation of the specific technology studied is listed chronologically in a database, as for example workshops on the technology, the start-up of R&D projects, expressions of expectations about the technology, or announcements of resources made available or removed. Incomplete information about (important) events is verified and completed by looking further into other sources and on the Internet.
2. **Database classification:** The database is structured according to year of the event, reference, event description, and event category (see representation below of a stylised database, Table 3.2).
3. **Allocation to functions:** Each event category is allocated to one System Function using the classification scheme, where specific event categories are allocated to specific System Functions. During this procedure, the classification scheme was developed in an inductive and iterative fashion (see Table 3.1). The classification scheme and event categories were verified by another researcher to improve reliability. Any differences in the coding results of the researchers were analysed and resolved.
4. **Summary data and graphical representation:** As a starting point for the analysis, the events are plotted in graphs per year and per System Function. Here, only the occurrence (positive or negative) of the event rather than the content is represented. The content and, thereby, the relative impact of the event on the System Function fulfilment, is subsequently elaborated in the narrative.
5. **Historical storyline (narrative)**: In addition to the schematic representation, a story is required that narrates the sequence of events unfolding over time, as the graphs can only represent *if*, but not *how* the change occurred upon the emergence of an innovation (Poole et al. 2000). Thus, to obtain a full understanding of how innovations processes take place, a narrative history or story depicting the order and sequence of events, has to be combined with the graphical representations. For each case study, a historical storyline and – if possible – graphical representations are provided (see explanation below for Table 3.1). This is a crucial step in the analysis, in which choices have to be made and the researchers' interpretations are included. To

increase the objectivity of this step, the narrative is checked by experts in the field (see also step 7).

6. **Identification of patterns, virtuous and vicious cycles:** By comparing the shapes of the graphs with the content of the storyline, patterns or cycles can be identified. For example, a virtuous cycle shows up in the graphs by a raising line; in the narrative, it manifests as a corresponding sequence of positive events influencing and reinforcing each other, as to build up momentum. The contrary is observed for vicious cycles: the graph shows a dropping line; in the narrative, negative events influence each other causing absence of other events.

7. **Triangulation of results:** The completeness of the data, the historical event description, and the results from the analysis are verified by experts in the field (via telephone, e-mail, or interview).

8. **Comparison of case studies:** For each case study, the same steps (1-7) are carried out, as to identify the same sort of patterns and cycles, and as to compare them with each other. Aim is to obtain a common explanation for the success or failure of technological change in the renewable energy field.

The Table below provides an overview of the System Functions and the event categories used to allocate the events to the System Functions. In the third column, the sign of the respective event category is represented. An event can either have a positive or a negative effect on the fulfilment of the respective System Function. For example, the discontinuation of the construction of a plant is categorised as 'project stopped', resulting in a negative fulfillment of entrepreneurial activity.

Table 3.1 Classification scheme for measuring System Functions

System Functions	Event categories	Sign
Function 1: Entrepreneurial Activities	Project started	+1
	Project stopped	-1
Function 2: Knowledge Development	Desktop/Assessment/Feasibility studies on the technology	+1
Function 3: Knowledge Diffusion	Workshops, Conferences	+1
Function 4: Guidance of the Search	Positive expectations of the technology; Government regulations	+1
	Negative expectations of the technology; Expressed deficit of regulations	-1
Function 5: Market Formation	Specific favourable tax regimes and environmental standards	+1
	Expressed lack of favourable tax regimes or favourable environmental standards	-1
Function 6: Resource Mobilisation	Subsidies, investments for the technology; Biomass streams allocated to the project	+1
	Expressed lack of subsidies, investments; Shortage of biomass streams allocated to project	-1
Function 7: Advocacy Coalition (Creation of Legitimacy/ Counteract Resistance of Change)	Lobby activities for the technology; Support of technology by government, industry	+1
	Lobby activities against the technology; Expressed lack of support by government, industry	-1

In the following table (Table 3.2), a small selection of genuine events from the databases is provided and described. For each System Function, one positive and one negative event is provided for illustration. In addition, other event categories are represented that do not fall under the System Functions.

The events retrieved from literature are listed chronologically in the database; they receive a corresponding event number. Subsequently. the reference of the event is listed and a description of the event is provided. The event description contains information that allows categorising each event and allocating it to the corresponding System Functions, as listed in Table 3.1. The table also shows that the description of the events contains much more information than merely the allocation of the event to a specific System Function. Causal relations between events, plus interactions between external events and events in the Innovation System can be retrieved from these empirical descriptions. Furthermore, the entire narrative is strongly influenced by these empirical descriptions. In other words, the events are much more than just a quantitative indication of the System Function fulfilment.

Some events are reported by several sources in an identical manner in the same time period. In this case, the event is listed only once, with all of the references, functioning as triangulation of the data, such as in the case of event numbers 3 and 6. Some events are repeated throughout the years (for instance event numbers 9 and 10); those are listed individually per corresponding year. However, the second event is labelled 'double' and is not allocated to one of the System Functions.

Another type of category is used for literature providing general descriptions of or information about technological characteristics (event number 12), generally about renewable energies (event number 18), activities abroad (event number 16), or changes external to the Technological Innovation System studied (event number 19). All of those categories will be referred to as 'context', as they are not events that directly influence the development, diffusion, and implementation of the biomass technologies studied and are, therefore, not allocated to any of the System Functions. Nonetheless, they are entered into the database since they might provide information useful for the narrative.

To summarise, the final outcome of the process analysis is a narrative (storyline) of how the development of the Technological Innovation System has changed over time and the role of the different System Functions in this development. This narrative is completed with and illustrated by several pictures in which the events are plotted over time. In the narrative, the focus lies on extracting patterns such as the cycles represented in Figure 2.2. Cross case analysis can subsequently be used to test whether these patterns are case specific or whether they hold more generally. Insights into these patterns are the first step towards policy recommendations regarding the governance of this set of Technological Innovation Systems (Hekkert et al. 2006).

Table 3.2 Examples of genuine events taken from the databases of biomass digestion, biomass gasification, and biomass combustion in the Netherlands and of biomass digestion in Germany

Nr	Year	Reference	Event Description	Event Category	F1	F2	F3	F4	F5	F6	F7
1	**1988**	Wim van Nes, Centrum voor energiebesparing and schone technologie (CE) in DE, 2, April 88 p.27	Minister Braks of Agriculture and Fishery will no longer invest in the development of manure digestion or existing plants.	Negative regulations	0	0	0	-1	0	0	0
2	**1991**	Haskoning, Report # 9103 Energie & Milieutechnologie, 1991	Heidemij Reststoffendiensten BV and WU set up a pilot plant using the BIOCEL conversion system. The investments in Biocel plants with capacities of 25,000 and 50,000 t/y are app. 3.75 Mio and 4.7 Mio Euros resp ectively. The processing costs for plants of 25,000 and 50,000 t/y are 33 and 12 Euros respectively. Per ton of agricultural waste, 70m^3 of biogas are produced, compared to 90m^3 per ton of organic waste.	Project started	1	0	0	0	0	0	0
3	**1992**	DE 5, November '92, p.22 "Gft-vergassing goedkoopst" Same as: E&MSpectrum, 1-93, p.5 "Vergassen GFT-afval goedkoper dan composteren"	The gasification of organic household waste is researched by NWS-UU. The waste is dried with process heat, gasified and converted into electricity by means of a turbine. The process costs for a 16MW-plant (30t per hr, 140,000-190,000t of organic waste per year) are 15 Euros per ton of organic waste. Since no compost is produced during gasification, and due to its lower production costs, this conversion system may become a realistic option. The practical problems (of cleaning the syn-gas from alkali- and heavy metals) can be solved.	Feasibility study	0	1	0	0	0	0	0

Nr	Year	Reference	Event Description	Event Category	F1	F2	F3	F4	F5	F6	F7
4	**1992**	DE 5, November '92, p.22 "Gft-vergassing goedkoopst" Same as: E&MSpectrum, 1-93, p.5 "Vergassen GFT-afval goedkoper dan composteren"	The practical problems (of cleaning the syn-gas from alkali- and heavy metals) can be solved.	Expectations	0	0	0	1	0	0	0
5	**1994**	E&MSpectrum, 11-94, p.28-31 "Reparatie van forse bezuiniging is nu eerste prioriteit; Energiewereld likt de wonden"	At the end of October, the Ministry of EZ announces a cutback of 81 million Euros for R&D, demonstration and application budget for new energy technologies, resulting in the reduction of many subsidies the following year. Institutes such as ECN have 3 years to adapt to the cutbacks.	Tax deficit	0	0	0	0	-1	0	0
6	**1995**	DE 1, 2/95, p.6-7 "Vijfde Nederlandse Zonne-energie Konferentie en Symposium Biomassa" same as E&MSpectrum, 5-95, p. 4 "Nieuwe beleidsdoelen zonne-energie en biomassa"	'5th Dutch Conference for Solar Energy and Biomass'. At this conference, themes such as Dutch and European Policies, energy crops projects, research activities, and different trial and demonstration projects for energy production are discussed. The project presented is the 'North-Holland Biomass Gasification Project' by NV UNA. The research presented is the 'National Biomass Gasification Programme (NOB)' and the 'Small-scale Gasification of Biomass for Electricity Production' by R. van den Broek, UU.	Workshop	0	0	1	0	0	0	0
7	**1996**	DE 3, p.9, 1996	Digestion of biomass is promising in the NL, for it is cheaper than composting. However, the firms that invested in composting are in control of the organic waste streams, therefore, the availability of organic waste is restricted and leads to delays for pilot projects.	Feedstock deficit	0	0	0	0	0	-1	0

Nr	Year	Reference	Event Description	Event Category	F1	F2	F3	F4	F5	F6	F7
8	**1998**	DE, August 1998, p. 22 "Vergassingsproject NH gaat niet door" same as Afval! Nr. 7, September 1998; same as Biovisie, September 1998, "Geen biomassavergasser voor Noord-Holland"	The province of North-Holland and energy company ENW (successor of PEN) decide to discontinue the ambitious biomass project on which they have worked for the past 5 years. The project repeatedly changed; in its final stage, it consisted of a biomass gasification plant. The gas produced would have been delivered to the UNA-centrale Hemweg in the city of Amsterdam.	Project stopped	-1	0	0	0	0	0	0
9	**1999**	Sueddeutsche Zeitung, p. V2/1, 1999, Matthias Hell	The programme is started by the BMWi. The budget is 100 Mio Euros (200 Mio. DM) per year to support solar cells, biogas, hydro and thermal installations. Applicants are private people, freelancers, and small and medium sized firms.	Research programme	0	0	0	0	0	1	0
10	**2000**	Agrarzeitung, March 4, 2000, p. 4 Haas, Gisela "Förderung des BMWi"	Since 1 September 1999, an annual sum of 102 Mio Euros (200 Mio.DM) is available in Germany to finance the 'Market Stimulation Programme' by the BMWi. According to the 'Bundesinitiative Bioenergie Bonn (BBE)', an annual sum of 36 Mio Euros (70 Mio.DM) is available for biomass, which is 35% of the total sum. The programme runs until 2002. Biomass and biogas plants will be supported; biogas plants that meet high environmental and technical standards will be supported according to size, i.e. from 19,000 to 153,000 Euros (38,000 up to 300,000 DM).	Double	0	0	0	0	0	0	0

Nr	Year	Reference	Event Description	Event Category	F1	F2	F3	F4	F5	F6	F7
11	**2000**	BMU (2000). Berlin, Federal Ministry for the Environment, Nature conservation and Nuclear Safety.	17 March 2000: 'Act on granting Priority to Renewable Energies/Act on Sale of Electricity to the Grid' (Gesetz fuer den Vorrang Erneuerbarer Energien, EEG). Obligation to purchase and compensate for Renewable Energy Sources. Remunerative arrangement per installed electrical capacity: up to 500 kW: 10.23 cents/kWh; up to 5 MW: 9.21 cents/kWh; 5-20 MW: 8.70 cents/kWh. From 1 January 2002 onward, the remuneration will be reduced by 1% for each newly built plant.	Feed-in system	0	0	0	0	1	0	0
12	**2002**	STROMEN, nr. 10, Jrg. 6, 25 Juni 2004, p. 7 "Vergiste mest niet slechter dan onbehandelde mest"	Digested manure is a good product to bring nutrients to the land. It has other characteristics, but it is not worse than undigested manure. The nutrients in the digested manure are released faster into the ground and, therefore, are absorbed faster by crops, resulting in a bigger yield. However, in cold or wet weather, the nutrients are drained off faster. Digested manure contains weed seeds with less germination power than undigested manure. (NOVEM)	Context Technology	0	0	0	0	0	0	0
13	**2004**	DE, Juli 2004, p.29 "Nieuwe stimulansen voor energieprojecten"	At the end of July, the government publishes the positive list of organic material that can be co-digested without permits. The 'digestate' can be used without having to apply for permits.	Regulations	0	0	0	1	0	0	0

Nr	Year	Reference	Event Description	Event Category	F1	F2	F3	F4	F5	F6	F7
14	**2004**	DE, March 2004, Nr. 3, p.14. Dik Tommel nieuwe voorzitter Platform Bio-Energie: 'Bio-energie moet zwaarwegend maatschappelijk belang worden' G. van Wijland	For 2004, the platform has a budget of 100,000 Euros. Most important areas are: - Obtain an important social interest for bio-energy; - Conclude an agreement with Bestuur Landelijke Ontwikkeling Bio-Energie (BLOBE); - Improve the MEP regulations; - Obtain a positive list for co-digestion; - Streamline permit regulations; - Include waste and agricultural sector in the Platform.	Lobby	0	0	0	0	0	0	1
15	**2004**	DE, February 2001, p.35 "Omwonenden verzetten zich tegen biomassacentrale"	Several inhabitants living near the 'Willem-Alexander' plant in the town of Buggenum are opposing the change of the coal gasification plant into a biomass gasification plant.	Resistance to change	0	0	0	0	0	0	-1
16	**2004**	STROMEN, 3 September 2004, 6de Jrg., Nr. 15, p. 3 "Klimaatneutral dankzij biodieselfabriek en houtvergasser"	The town of Gussing in Austria has its own energy production, biodiesel from rapeseed and gaseous fuel from the gasification of wood, all of which come from the region.	Context Foreign	0	0	0	0	0	0	0
17	**2004**	STROMEN, Nr. 8, 8 May 2004, 6de jrg, p.7 "Fusie tussen Senter en	On 1 May, Senter and NOVEM merge.	Context Institution	0	0	0	0	0	0	0
18	**2004**	STROMEN, 22 Oktober 2004, Nr. 18, p. 6 "Opinie: De nieuwe energietransitie in het licht van de vorige"	Background article about the energy transition in the NL: 1950 – present.	Context General	0	0	0	0	0	0	0

Nr	Year	Reference	Event Description	Event Category	F1	F2	F3	F4	F5	F6	F7
19	**2004**	Stromen, nr 13/14, 13 augustus 2004, p.6 "Hoge olieprijs moet investeerders dwingen tot duurzame innovatie" Paul Metz	When oil prices increase, several different associations may rise. Most common are: "It is bad for the economy" and: "Shell and others profit from it." However, a high energy price can also lead to more investments in saving energy or switching to other energy sources. This is what belief in the market teaches; however, such changes only occur if investors are sufficiently convinced that the oil price will remain high for a long period of time.	Exogenous	0	0	0	0	0	0	0

Notes

1 Since the case studies have not all been successful, most of the System Functions have not – or only marginally – been fulfilled. Therefore, in this thesis, no comment can be made whether a System Function is successfully fulfilled when a certain threshold is reached.

2 Poole and Van de Ven label an event 'the smallest meaningful unit in which change can be detected.' In this thesis, this definition is applied.

3 Path dependency implies that each case may have a somewhat different set of forces acting upon it, depending on the specific events that occur during its development (Poole et al. 2000)

4 The Lexus Nexus ™ academic news archive contains all articles that have been published from 1990 onwards. The relevant articles can be found by means of a keyword search.

4 Biomass energy technologies

In this paragraph an overview of the three biomass conversion technologies for the supply of heat or electricity is given.

4.1 Biomass and its potential

Among renewable energies, biomass has a high potential due to its large resource base and versatile energy applications. Biomass is defined as "all organic material produced by plants or any conversion process involving life is called biomass. Biomass is labelled as green house gas emission neutral energy source since it has a short carbon cycle, i.e. emission of CO_2 from plant to atmosphere and absorbed by the plant during growth only takes between one to some tens of years, whereas fossil carbon exists for million of years" (ECN 2006). Biomass provides about 80% in the form of combustible renewables and renewable waste to the worlds total primary energy supply (IEA 2006). In addition, biomass can be converted into bio-energy via several ways, i.e. thermal (combustion, gasification, pyrolysis), biochemical (anaerobic digestion and fermentation) or mechanical (extraction) conversion routes. Below the technologies focused on in this thesis (digestion, combustion, gasification and co-firing) will be described in more detail.

4.1.1 Biomass digestion

Anaerobic digestion is a low-temperature biochemical process, through which a combustible gas – biogas – can be produced from biomass feedstock. Biogas is a mixture of carbon dioxide (CO_2) and methane (CH_4), which can be used to generate heat and/or electricity via secondary conversion technologies like gas engines and turbines (see Figure 4.1 Schematic representation of the digestion process) (IEA; TheBiomassSite; BioGen 2002).

High moisture biomass feedstock (e.g. organic waste or manure) is especially well suited for the anaerobic digestion process (IEA; TheBiomassSite; BioGen 2002). The feedstock is placed into a digester, a warmed, sealed airless container. The digestion tank is continuously stirred and heated to around 35°C to create the ideal condition for biogas conversion. Although there is a constant inflow and outflow of material, the average retention time is 18 days. This allows a significant percentage of the organic solids to be converted to biogas. The outflow of the digesters can be in two forms: biogas and a liquor/fibre mixture, known as 'digestate'. The gas from the digesters is stored to control the flow into the engine and this engine is used to generate heat and electricity for on-site or off-site use.

Digestion can occur in two different kinds of plants, either farm-scale, where the biogas is produced and used by one farm, or by centralised plants, where the biomass is collected from several sources. The feedstock used can vary from manure or organic waste only, to a combination of manure with organic waste or agricultural surplus, called co-digestion. By adding organic waste sources to the manure higher yields of biogas is obtained.

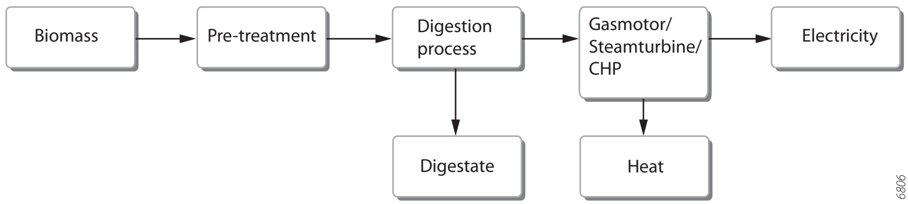

Figure 4.1 Schematic representation of the digestion process (Novem 2003)

4.1.2 Biomass Combustion and Biomass Gasification

The traditional way to convert biomass into electricity is by means of biomass combustion. Basic combustion concepts include pile burning, various types of grate firing (stationary, moving, vibrating), suspension firing and fluidized bed concepts. Typical capacities for stand-alone combustion plants (typically using wood such as forest residues, as fuels) range between 20-50 MWe, with related electrical efficiencies in the 25-30% range (Faaij 2006b). In the combustion process the biomass is combusted where the hot exhaust gases are used to produce steam that is processed through a steam turbine to generate electricity (see Figure 4.2 Schematic representation of the combustion process).

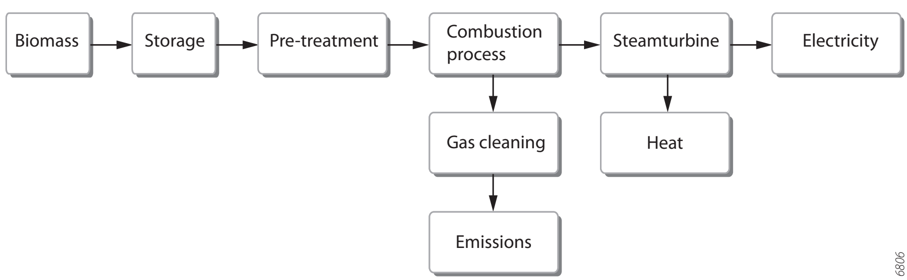

Figure 4.2 Schematic representation of the combustion process

An innovative and more efficient method is gasification of biomass. In this case biomass is combusted in an oxygen-starved environment, where the end products are CO and H_2 gases (so called producer gas or syn(thesis) gas) (see Figure 4.3 Schematic representation of the gasification process). In contrast to solid biomass, this producer gas can be fed into a gas turbine to produce electricity at a much higher efficiency (35-40%) than combustion (25-30%) (Williams and Larson 1996; Faaij et al. 1997b; Morris et al. 2005).

A distinction between smaller scale gasification and larger scale gasification can be made.

Smaller scale gasification has a capacity range between 10's of kWth to about 1 MWth, generally involving fixed bed gasification concepts. For smaller scale gasification, downdraft or updraft, fixed bed gasifiers with capacities of less than a 100 kWth up to a few MWth are developed and tested for small-scale power and heat generation using diesel and gas engines (Faaij 2006b). Small-scale gasifiers have critical demands with respect to fuel quality, such as

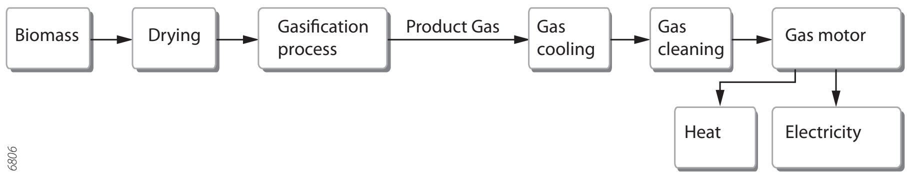

Figure 4.3 Schematic representation of the gasification process

preferably standardised and hence more expensive fuels such as pellets. In addition severe emission standards require effective gas cleaning that increases the costs. No standardised gasification system using fuel cells and micro-turbines and small scale gas cleaning procedures are available yet, increasing the costs as well and hampering breakthrough (Faaij 2006b).

Larger scale gasification has a capacity range between several 10's of MWth, where mainly Circulating Fluidized Bed (CFB) is used. CFBs have high fuel flexibility. Gasifier beds at atmospheric pressure (ACFB) are used for production of (raw) producer gas and process heat but are not diffused in large numbers (Faaij 2006b). Biomass Integrated Gasification/Combined Cycle (BIG/CC) systems combine flexibility with respect to fuel characteristics with a high electrical efficiency. Electrical efficiencies around 40% (LHV basis) are possible on a scale of about 30 MWe on shorter term (Faaij et al. 1997b; Faaij 2006b). BIG/CC can achieve low emission levels to air levels, because the fuel gas needs severe cleaning prior to combustion to meet gas turbine specifications (Faaij et al. 1997b; Faaij 2006b). However, several technological issues, such as concerning pre-treatment and tar removal, still need to be resolved, resulting in a very slow development of biomass gasification in a rapid liberalised energy sector (Faaij 2006b).

In this thesis the focus lies on electricity production, therefore the application of biomass gasification for the production of transportation fuels (e.g. Fischer-Tropsch fuels) is not included, also because it is developed in quite a different innovation system.

Specifically for the Netherlands the only biomass gasification plant constructed will be described in Chapter 6. The biomass gasification plant at the Amer Power Plant in Geertruidenberg is designed to process 150,000 ton of waste wood per year, in an atmospheric circulating fluidized bed, with sand bed material, at an operating temperature of 850 and 950°C (EssentEnergieBV 2001). The product gas produced is cooled and cleaned to remove particulate material, ammonia and condensable tar materials. The cleaned gas is then reheated and fed to the burners in the coal-fired furnace (this step is also called indirect co-firing) (Loo and Koppejan 2002). The gasification unit is rated at 83 MWth, and the coal-fired boiler at 600 MWth (Loo and Koppejan 2002).

4.1.3 Co-firing of biomass in coal plants

Co-firing is a method of combining fossil and bioenergy fuels in conventional power plants. The simplest form is to use biomass in a coal fired power plant, where the biomass is carried with the pulverised coal to the boiler (see Figure 4.4). It is important that the biomass has the same properties as the coal, i.e. it has to be ground into very small particles and in the process

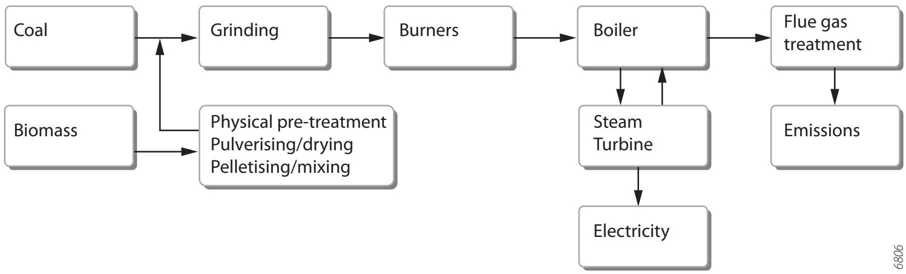

Figure 4.4 Schematic representation of direct co-firing process (based on (Konings 2006))

acquire flow properties. The proportionate part of the calorific value of the biomass used can be considered as renewable energy (ECN 2006). The typical size of power plants where co-firing is applied to is between 50 MWe and 700 MWe, which are equipped with pulverised coal boilers, such as bubbling and circulating fluidized bed boilers, cyclone boilers, and stoker boilers (Loo and Koppejan 2002). There are three different co-firing concepts as described in Loo and Koppejaan (Loo and Koppejan 2002):

i. Direct co-firing: where the pre-processed biomass is directly fed to the boiler furnace (most plants in the Netherlands operate according to this principle);
ii. Indirect co-firing: the biomass is first gasified where the product gas produced is fed into the boiler furnace (e.g. Amer plant unit 9).
iii. Parallel combustion: the biomass is combusted in a separate boiler and the utilisation of the steam produced within the power plant.

Results

This part of the thesis will be divided into five chapters. The first four chapters will contain the narrative, functional analysis and conclusion for each case study. The fifth chapter will discuss methodological results.

5 Biomass digestion in the Netherlands from 1980-2004[1]

5.1 Introduction

Since the 70's research on energy conversion technologies, such as biomass digestion, has been carried out in the Netherlands. However, after thirty years biomass digestion has not been implemented successfully on large-scale. Therefore the research question is:

How can we explain the low diffusion of biomass digestion technology in The Netherlands?

The aim of this chapter is to create insight in the underlying factors of this troublesome trajectory by applying the System Functions framework. This results in a clear understanding of the (lack of) activities that took place in the biomass digestion Innovation System and the role of government policy. The analysis provides several lessons to take into account when developing policies for the acceleration of the development and application of biomass energy.

5.1.1 Notes on Methodology and technical aspects

The theory and methodology as described in chapter 2 and 3 are applied to this case study. In the historical analysis the key processes, more in particular the virtuous and vicious cycles, that took place within the biomass energy Innovation System, are highlighted. The symbols F1 – F7 refer to the seven System Functions as described in Chapter 2.4.

The chronological description of the events (the storyline) has been checked with experts of the field[2].

The analysis of biomass digestion is restricted to the digestion of manure, organic- and agricultural waste. Digestion of wastewater is not included. The reason for not including this stream results from that it involves a totally different innovation system with different actors and different institutions. Furthermore the technological factors affecting the diffusion are not the same due to the difference in feedstock.

5.2 Historical overview of Biomass Digestion from 1980-2004

In this paragraph a chronological description of the events that took place in the biomass digestion trajectory is presented. The description will be subdivided into different periods. The end of each period is chosen on the basis of change in activities or key events, therefore not all periods are equal in length.

5.2.1 The pioneers era, 1974-1987

The beginning of this period is characterised by pioneers setting up the first experiments on manure digestion, due to high and increasing energy prices as a result of the oil crises in the previous decades. Digestion of manure seems a promising option to convert a waste product (manure) into useful energy. Several farmers are enthusiastic about this option and digestion installations are set up on several farms (Verbong et al. 2001). Developers of digestion equipment, such as Paques, see a great market opportunity to install digestion equipment on farms. As a result the number of digestion plants on farms increases between 1979 and 1983, and consequently the application of digestion moves from laboratory scale to practical scale (Nes 1988). However, a survey on the functioning of the digestion plants built on farms shows that there are many technical and economical problems. Nonetheless, it is believed that the problems are solvable and so the 'Netherlands Ministry of the Environment' (VROM) constructs a trial plant in Assendelft within the framework of the "National Research Programme for Recycling of Waste" (NOH programme) (Nes 1988). However, shortly after its construction the plant is shut down, due to the decrease of conventional energy prices resulting in a lack of profits, technical problems and complicated permit regulations (Nes 1988; Verbong et al. 2001).

Here the lack of supporting policies forms a barrier, in addition to the technical and economic problems (E&S 1982). The government shows a lack of vision and strategy regarding the development and introduction of renewable energies in general, be it on short- or long-term, small- or large-scale, centralised or decentralised energy projects(E&S 1982). For digestion the situation is even worse, since digestion is not seen as a key renewable energy technology that will contribute to the national energy supply like biomass combustion (Blok 1985b).

Around 1985 the manure surplus in The Netherlands becomes an urgent problem. Several strategies to solve the problem are explored. One solution is to convert very wet manure streams into dry fertilizer that can easily be exported or transported to other parts in The Netherlands where there is a manure shortage. Digestion is seen as a means to reduce the energy demand of these manure conversion plants. The government support for manure digestion is from that moment only framed in the context of the manure problem and not in terms of its potential contribution to renewable energy. This is perceived as a great disappointment by the renewable energy lobby (Blok 1985b; Verbong et al. 2001). In addition to technical problems and the lack of supportive policy there is a drastic drop of oil prices in 1986 resulting in decreasing profits for biomass digestion (Lysen et al. 1992b). Additionally Minister Braks of Agriculture announces in 1986 that no more money and support will be given to the further development of manure digestion nor to already existing projects, due to the technical problems and the reduced fossil fuel energy prices, resulting that digestion becomes expensive and unprofitable (Nes 1988). The result is that by the end of this period hardly any activities occur around the development or diffusion of biomass digestion technology. Clearly, the guidance of search is not in favour of digestion.

5.2.2 Impulses and inconsistency around digestion, 1988-1995

Nonetheless the discontinuity of activities in the previous years, some activities are picked up again. In 1986 the community Deersum, Friesland has some plans to build a central manure digestion plant in combination with a wind turbine, which provides the village with electricity and makes it self-sustained. The wind turbine is in operation in August 1987 and the digestion plant at the beginning of 1988. The first year is used for experimentation and collecting performance data. For the digestion plant several start-up problems occur: congestion of the manure pumps, high content of hydrogen sulphide (H_2S) and low electricity production of the combined heat and power (CHP) plant. Most of the problems are solved, however the costs for this installation remain high (Nes 1989). The plant closes in 1994 due to technical problems and a poor economic performance.

Another centralised plant, the largest ever built in the Netherlands, is set up around 1987 in the southern Netherlands in Helmond, by the first manure-export venture, Promest B.V. (Henley 1991). The aim is to convert 600 000 ton manure (15% of the Dutch pig manure) into 75 000 ton manure-grains, which are exported to Spain and Portugal (Didde 2004). However, several technical problems, such as corrosion problems and foam formation, hamper a smooth and full capacity running of the plant (Raven 2005). Finally, the plant is closed down in late 1994, since the supply of manure remains too expensive and the technology is not robust enough (Henley 1991; Holm-Nielsen and Al Seadi 1998b; Holm-Nielsen and Al Seadi 1998a; Didde 2004).

In 1988 digestion comes on the political agenda due to the expectation that much biomass waste will become available in The Netherlands. Due to land filling capacity problems, plans are made to stimulate households to separate organic waste from other waste. These organic waste flows are to be converted into compost, which can be used in agriculture and households as organic fertilizer to improve soil quality. The traditional conversion method for organic waste is aerobic fermentation (composting), which does not produce energy, but the large organic waste flows also feed the idea that it can be used as sustainable energy resource by means of digestion (Nes 1988).

In 1989 the Ministry of Economic Affairs (EZ), VROM and NOVEM commission a programme called 'Energy production from waste and biomass' (EWAB) with the aim to promote the use of waste and biomass as energy source. Within the framework of the EWAB and NOH programme several research, evaluation, feasibility and comparative studies of several plants are carried out and platforms are set up for biomass digestion (NOVEM 1992; Haskoning 1992b; Haskoning 1992c; E&MSpectrum 1993a).

In 1990, researchers at the University of Wageningen and engineering consultant Heidemij, set up a plant using the Biocel conversion system and another two plants are set up in Lelystad and Tilburg (Haskoning 1991; E&MT 1991b). These latter two plants are supported by the Ministry of VROM to make digestion the spearhead within the programme 'CO_2-emission reduction via waste regulation' of Senter[3] (Brinkmann 2000).

Another plant is built in 1993 called 'Greenery' in Breda, where the leftovers of the fruit and vegetable auction are digested (Zoeten et al. 1992).

In this same year, a decree on the 'quality and use of organic manure/fertilisers' (Besluit Kwaliteit en Gebruik Overige Organische Meststoffen, BOOM) is introduced which determines the quality and composition of a non-manure organic based fertiliser. The aim of this regulation is to build trust in the quality and purity of organic waste compost in order to stimulate demand (MilieuMagazine 2001; Reumerman 2004).

In 1994 the already expected large-scale collection and separation of organic waste is introduced in the Netherlands (Brinkmann 2000). Therefore the feedstock part is well taken care of for digestion. However, in October 1994 the Ministry of EZ announces a cut back of 81 million euro from the R&D, demonstration and application budget for new energy technologies (Vos 1994). The cut of the budget forms a real threat to the research, development and market introduction of renewable energies in general, since they are not profitable without subsidies yet (E&MSpectrum 1994). The EWAB programme budget is reduced from 3.6 million euro to 2.5 million euros (E&MSpectrum 1994). Research institutes such as the Energy Research Centre of the Netherlands (ECN) and the Netherlands Organisation for Applied Scientific Research (TNO) suffer most from the R&D cut backs. On top of the misery for the entire sustainable energy sector, the problems for digestion are even worse since the Ministry of Economic Affairs announces that only biomass combustion and gasification are supported but not digestion (E&MSpectrum 1994). The consequences are seen shortly after when the combined digestion plant and wind turbine in Deersum, Friesland is shut down, due to technical problems and the political unwillingness to further support digestion (DE 1994c).

The sustainable energy lobby complains that biomass digestion is not seen as a promising technology for large-scale energy supply and the fact that farmers are not stimulated enough to use manure for manure digestion, instead of just spreading it on the land (Daey Ouwens 1993). In several publications biogas production is predicted to be only profitable if there are more subsidies allocated to digestion and the fossil energy prices are high (Daey Ouwens 1993; E&MSpectrum 1993b; Vos 1994).

A potential solution for digestion is the so-called co-digestion technology. This implies that organic waste is added to the manure in order to produce much higher quantities of biogas. This would lead to much better returns on investments. However, in the Netherlands co-digestion is not feasible since it is unclear which types of organic waste flows can be mixed with the manure. This is a problem since the quality requirements of the produced digestate are very strict and farmers do not know how different organic additives to the manure influence the final digestate quality. In neighbouring countries lists with substances that are allowed are available, leading to many co-digestion initiatives (Raven, 2005). A lobby starts asking the government to come up with a list of allowed organic substances but it takes until 2004 before this is finally published (Haskoning 1993). A prime reason for this delay is the already existing manure surplus in The Netherlands, resulting that policy makers are not eager to increase the total manure flow by adding organic waste to manure in digestion plants (MilieuMagazine 2001).

5.2.3 The rollercoaster continues, 1995-2004

This period is marked by the closure of several plants set up in previous years. The organic waste digesters have a hard time due to several reasons. First it proves to be technically very difficult to digest organic waste flows from households since it contains much woody material (from thinning). Second, the composting of waste proves to be much cheaper then digestion, leading to the situation that composting plants are more successful in organising sufficient feedstock from the market. Finally, it is problematic to find enough end-uses for the digestate (Janse 1996a; Janse 1996b; Abbas 1998). As a result the plants constructed in Helmond, Breda and Tilburg are shut down (Janse 1998).

Furthermore, a general political uncertainty overshadows this period, since the government formulates no common and consistent regulations. For instance, the Ministry of Economic Affairs publishes the 'Third White Paper on Energy'[4] but doesn't provide any common strategy on the technical and economical development of bio-energy on how to achieve the goals of the White Paper (EZ 1995). From a benchmarking study it appears that the size of investments and the number of policies in the Netherlands is very broad and the technical potential is still small, resulting in high costs (E&MSpectrum 1998). This triggers several actors to unify the scattered initiatives of the pioneers by setting up platforms and information centres and to build a coalition to counter the critical voices that do not see biomass digestion as a promising technology (NOVEM 1998). Furthermore by 'joining forces' they hope to obtain an exemption from the 'regulating energy tax' (REB) for electricity produced from biogas (DE 2000)[5].

Since the organic waste digesters are not successful, in 1999 a different concept is tried. It leads to the construction of the largest digestion plant for organic waste in Groningen build by VAGRON. The plant is a demonstration plant for on site separation of integral household waste into different fractions, where the 'organic wet fraction' is digested and the rest of the integral waste is incinerated. The biogas produced is used to increase the electrical efficiency of the waste incinerator (DE 1999a; ECN 1999; Stromen 1999; Vermaat 1999).

Even though the circumstances for manure digestion have not changed, pioneers and idealists supported by Academia and the Dutch platform for Sustainable Energy keep developing initiatives. This leads to three demonstration centres for digestion of manure on farms, 'Nij Bosma Zathe Goutun', 'Sterksel' and 'De Marke' (DE 2002a; ECOFYS 2003; Stromen 2003a).

Nonetheless, the impulses and efforts to establish digestion as a solution for several problems, i.e. manure surplus, waste treatment and climate change, the development and application of digestion is still delayed due to inconsistent policies and regulations. There is a call for the government to provide more financial security, facilitate the permit application procedures and provide a level playing field (DE 2002b). Additionally, since the election in 1998 it is not clear which direction the government will take with respect to financial support, such as the energy tax, since such regulations are still very important for the development of digestion to become a self-sustained technology (DE 2002c). An example of financial and political uncertainty is the delayed introduction of the 'Environmental Quality Electricity Production' (MEP) regulation. This regulation subsidises the electricity production of renewable energy for 10 years, by which the – till then rather low – economic performance of most biomass technologies is improved (EZ 2003). Therefore the Dutch Agency for Renewable Energies (PDE) lobbies to qualify all forms of digestion, except from dump gas and waste water treatment installation, for the MEP (DE 2003b-b).

The year 2004 seems to be the crucial year for manure digestion. Finally after long years of struggling the regulations for co-digestion are altered. Minister Van Geel (VROM) and Minister Veerman (LNV) revise the complicated regulations and policies around manure digestion and farmers are finally allowed to add some organic material to the digestion of manure. Further, the Ministries will develop a list of organic substances that will allow co-digestion. In addition clear directives will be developed for the set up and testing of environmental permits (Stromen

2004a; Wijland 2004c). Due to this 'green list' and simplified permit procedure, experts expect an increase of biogas plants on farms. However, the real breakthrough for dozens of large biogas plants is expected to be achieved only if the government releases the second half of the 'green list', where also products from the food industry, such as frying fat and swill will be included (TW 2004; Zoethout 2004; Stromen 2004b-b). Finally there is enough feedstock available for digestion and some improvements are made for the output of digesters. Digestion and production of biogas is recognised as a sustainable energy technology and a MEP subsidy of 9.7 euro cent per kWh is granted for a period of 10 years.

However, since a plant has an estimated pay-off period of 6-9 years, only a period of profit of one to four years is then available, which can be considered as too short. Therefore a lobby continues for a longer MEP subsidy to make the return on investments more interesting, however the financial climate for digestion has never been as positive as today (DE 2003a; DE 2003b-b; Stromen 2004b-a). This results in many initiatives to put digestion on agricultural agenda like symposia and workshops (Stromen 2003a; Stromen 2004a; Stromen 2004b-a; Stromen 2004b-b). Still, the future needs to shed light whether the change in legislation is powerful enough to create many entrepreneurial activities leading to a large diffusion of digestion in The Netherlands.

Finally, to sum up the whole period of 30 years, it can be said that the development of biomass digestion has been very sporadic and fluctuated substantially. There have been a lot of political and financial uncertainties, due to changing governments and unanimity between the Ministries on biomass digestion. There has been no continuity and stability in government regulations longer than a few years, as to allow an increase in activities around biomass digestion. Biomass digestion was always only seen as a temporary solution to several current problems but never as long-term alternative, i.e. reduce manure surplus in the 80's, waste surplus and CO_2 emissions in the 90's, because in the end other technologies, such as combustion or composting were preferred. However, in 2003-2004 the regulations for co-digestion are finally altered, which might bring along the long awaited breakthrough for digestion technology.

5.3 System functioning

In this paragraph we will answer the research question 'how can we explain the low diffusion of digestion in the Netherlands?' by means of analysing the functional pattern of the digestion innovation system.

At the beginning of the period 1974-1987, pioneers develop entrepreneurial activities (Figure 5.1) and some knowledge is created (Figure 5.2). The actions are not strongly coordinated and a lobby for better institutional arrangements is lacking since only a very limited number of activities can be classified as advocacy coalitions (Figure 5.6). This first period is also characterised by a lack of activities in terms of system functions such as guidance (see very low number of positive guidance activities in Figure 5.4), market formation (no graphical representation due to little data) and resource allocation (see the complete lack of resource mobilisation in this period in Figure 5.5). Thus, the initial experiments fail to lead to the build up of other system functions that are needed to propel this emerging technology. The consequence is that after technological

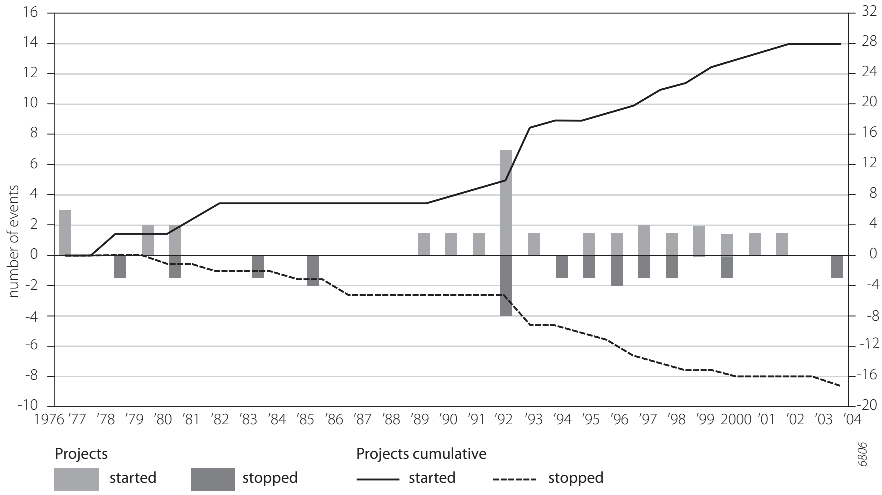

Figure 5.1 Activity pattern of System Function 1: Entrepreneurial Activties

disappointments no continuation of activities takes place (see the negative lines in Figure 5.2 that represent the projects stopped between 1978-1985; see Figure 5.4 negative lines in 1983, 1985 and 1986 representing lack of guidance). This results in a temporary stop of activities, and hardly anymore functions are fulfilled.

Between 1989 and 1994 an impulse for biomass digestion occurs, due to the compulsory collection of organic waste (see Figure 5.4), which is an interesting resource for biomass digestion, so that it is rediscovered as promising technology. Now we see a boost of research activities due to government programmes (see peak in Figure 5.2). This is accompanied by knowledge diffusion activities (see peak in 1992 in Figure 5.3). We also observe the construction of several plants (see increase in the positive cumulative line in Figure 5.1 since 1988). However, even though the government gets involved in stimulating knowledge development, this does not lead to acceleration in the construction of digestion projects (this can be seen in the cumulative

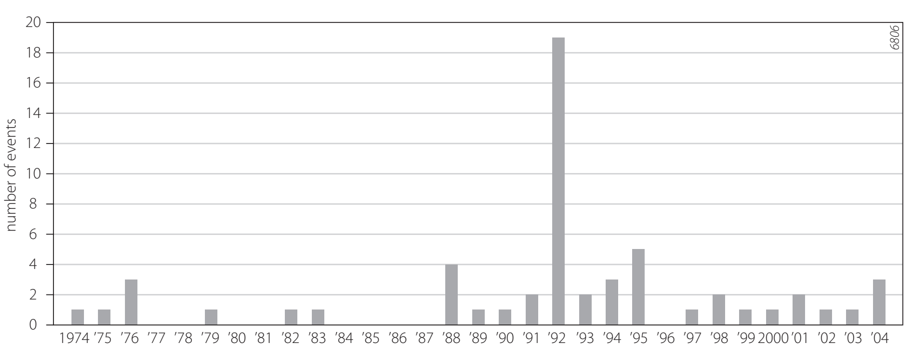

Figure 5.2 Activity pattern of System Function 2: Knowledge Development

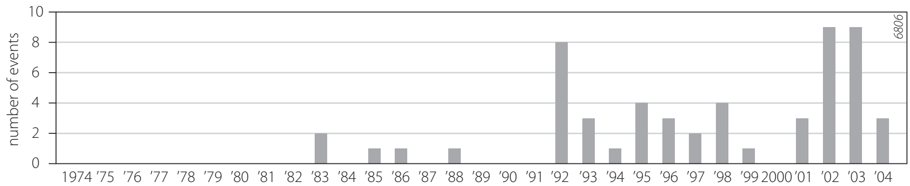

Figure 5.3 Activity pattern of System Function 3: Knowledge Diffusion

negative line in Figure 5.1 that depicts the closing of digestion plants). An explanation that acceleration does not take place can be found in the functions guidance of the search (Figure 5.4) and resource mobilisation (Figure 5.5). Figure 5.4 does not show a strong increase in positive guidance activities; In fact, every positive statement seems to be alternated by negative statements. This underpins our empirical story in which we show that digestion was never seen as a key technology in terms of renewable energy and that the government has been openly quite negative about this technology. Figure 5.6 shows that during this period actors complain regularly about the lack of financial support for this technology.

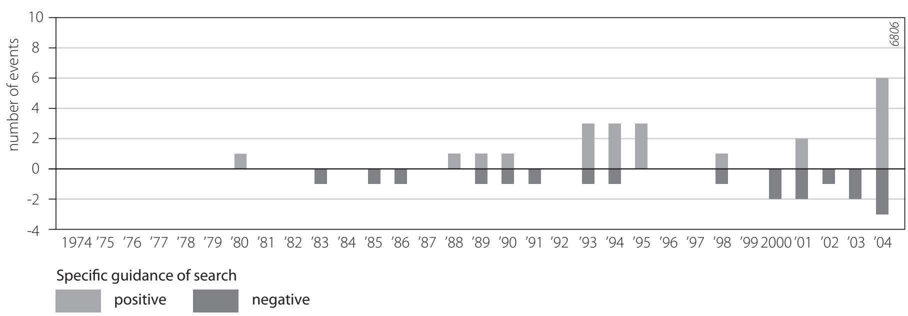

Figure 5.4 Activity pattern of System Function 4: Guidance of the Search

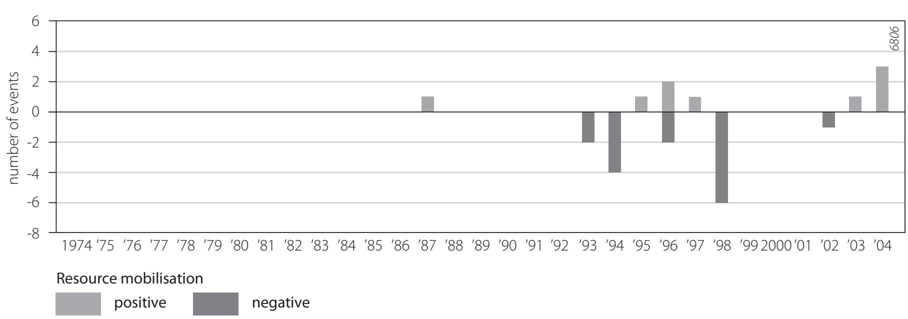

Figure 5.5 Activity pattern of System Function 5: Resource Mobilisation

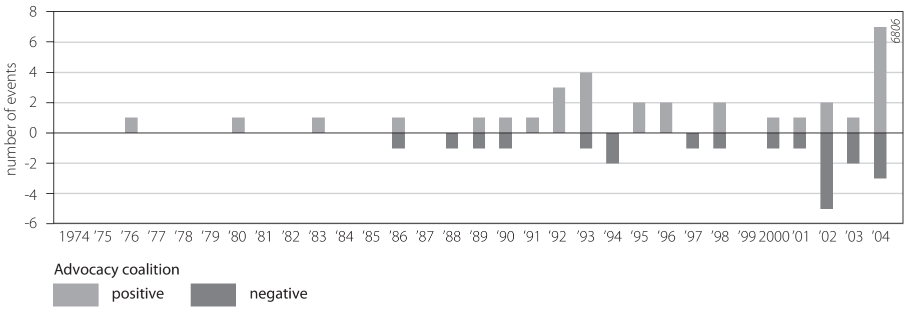

Figure 5.6 Activity pattern of System Function 7: Advocacy Coalition

The final period 1995-2004 is marked again by the incoherent guidance of the government and a shortage of financial resources (see Figure 5.4 and 5.5). In addition there are still severe technological problems and as a result, most of the plants are shut down (see Figure 5.1). Finally a lobby for better circumstances for digestion picks up (see peak in Figure 5.6 in 2004). This will have most likely contributed to the very important changes such as favourable regulations that make co-digestion possible and a much better financial situation due to decent feed-in tariffs for biogas based electricity. This again gives new impulses to the biogas scene and a general increase of activities from 2002 onwards is observed and a further increase in activities is likely to take place in the coming years.

5.4 Conclusions

How can we explain the slow diffusion of biomass digestion in the Netherlands? The dynamic analysis of the functioning of the Biomass Digestion Innovation System shows problematic functional patterns. Not one of the System Functions that were analysed showed a continuous build up over the years. Regularly short periods of entrepreneurial activities by enthusiastic pioneers occur but this does not lead to positive feedbacks with other System Functions. Thus, the system never gains enough critical mass to overcome the technological problems. Furthermore, the institutional environment in which this Innovation System needs to function is unstable and very often not stimulating for digestion initiatives. In turn the biomass digestion community is often unable to successfully lobby for improved institutional arrangements. Not many network and lobby activities are observed, neither many joint initiatives between academia, research institutes and local projects. It seems that the promise and expectations around digestion technology are not able to mobilise a persistent group of actors that push forward this technology, also in difficult times. On the other hand it is understandable that it is difficult to form a strong digestion network when the institutional framework is strongly fluctuating over the years, creating much uncertainty and is only sporadically in favour of digestion. Thus, what we see is a misalignment between government actions and the needs of entrepreneurs.

Policy lessons for an improved development and diffusion of biomass digestion follow directly from the above. Government policy should have focused on strengthening three System

Functions: Guidance of the Search, Market Formation and Resource Mobilisation. Specifically, this involves long-term, clear and supportive arrangements concerning the economics of biomass digestion plants, e.g. fixed feed-in tariffs for the electricity produced. This creates a market for digestion and due to the long-term character it guides entrepreneurs in their choice for this technology. Furthermore, supportive regulations regarding co-digestion (especially allowing carbon rich feedstock) would have greatly affected the developments. This would greatly influence the economics of digestion plants and resolve many uncertainties. We expect that by removing these two bottlenecks the biomass digestion community will grow and start fulfilling the other System Functions that are necessary for the development and diffusion of biomass digestion.

Notes

1 Originally published as Negro, S.O., M.P. Hekkert and R.E. Smits. (2007) "Explaining the failure of the Dutch innovation system from biomass digestion – A functional analysis". Energy Policy 35: 925-938 (Negro et al. 2007)

2 Personal communication via telephone: Rob van Ree, researcher at ECN, (March 2004); Mr W De Boo, De Boo & Partners (March 2004); Gerjo Koskamp, Praktijkcentrum De Marke (March 2004); Ms Annemarie van Lierop, Praktijkcentrum 'Sterksel' (April 2004);
Personal communication via e-mail: Mr. Patrick Reumerman, Senior Consultant, BTG biomass technology group B.V. (October 2004); Mr. Johan F. M. Raap, CSM Suiker BV, Centraal Laboratorium Afdeling Technologie en Milieu (October 2004); Mr. Thijs Oorthuys Grontmij Nederland bv Cluster Infrastructuur en Milieu Afdeling Water & Reststoffen (October 2004); Mr Kees Kwant, programme leader at SenterNovem (October 2004); Mr Henk Kasper, manager renewable energy production at Essent Energy (November 2004).

3 Senter is a financing agency under the Dutch Ministry of Economic Affairs

4 In Dutch: Derde Energie Nota; The aim is to achieve a 10% share of renewable energies in 2020 where biomass should contribute 44% (EZ 1995)

5 In The Netherlands conventional electricity is taxed with REB, whereas renewable electricity is not. This should reduce the gap in production price, however a lobby was necessary to argue that manure and organic waste should be seen as a renewable energy source as well.

6 Biomass digestion in Germany compared to biomass digestion in the Netherlands[1]

6.1 Introduction

Since the oil crises in the 70's research for alternative energy sources is carried out. However, not until the Kyoto protocol in 1997 do governments engage in serious commitments (UNFCCC 1997). In 1999 the German Government sets as a target that the share of renewable energies to the energy supply is to be doubled by 2010 (BMU 2000; BMU 2002). In this context, biomass plays an important role since half of the renewable energy is expected to be provided by biomass, due to its high potential and versatile applications (conversion to electricity, heat, biogas or biofuels) (Berenz 2003; IE 2005). Germany managed to realise this target[2], due to the successful implementation of biomass digestion technology (BMU 2006b). As recent results show, between 1995 and 2000 the number of plants increased from 300 to 1000, and in 2004 there are more than 2000 plants with a capacity of nearly 400MWe, which is ten times more than in 1994. For 2006 a doubling of the number of plants is expected (BBE 2004; Börnecke 2004; Siehoff 2004).

The introduction shows that the diffusion and implementation of biomass digestion technology is successful in Germany and can be found among the top five successful countries (e.g. electricity production from biogas in the European Union in 2005 (in GWH): Germany 5564 compared to UK 4783 (only landfill and sludge gas), France 460 and Denmark 274) (EurObserv'ER 2005). In this paper the German case is analysed as an example of a well functioning Innovation System approach and an attempt is made to draw lessons, more in particular for the Dutch case[3].

Therefore, the research question of this paper is: *How can we explain the high diffusion of biomass digestion technology in Germany and which lessons can be drawn for the Netherlands from German experiences?*

In this chapter it is shown that the System Functions interact with each other and lead to a positive build up (virtuous cycle). This build up enables the alignment between the institutional framework within which the technology is developed, on the one hand, and the technical requirements on the other. Especially the fulfilment of the System Functions, such as Entrepreneurial Activities, Guidance of the Search and Advocacy Coalition formation, explain the success of the biomass digestion technology.

6.1.1 Notes on Methodology and technical aspects

The same theory and methodology as described in chapter 2 and 3 are applied to this case study. In the historical analysis the key processes (virtuous and vicious cycles) that took place within the biomass energy Innovation System are highlighted. The symbols F1 – F7 refer to the seven System Functions that are the focus of this thesis as described in Chapter 2.4.

There are two types of biomass digestion plants in Germany, the decentralised, farm-scale plants (EHA[4]) and the centralised, large-scale plants (BGA[5]). In the south and southwest of Germany mainly 'decentralised, farm-scale plants' with a capacity of less than 70 kW dominate, whereas in the north and eastern federal states[6], 'centralised, large-scale biomass digestion plants' with an average capacity of 200 kW can be found (E&M 2002; Umbach-Daniel 2002). The differences in the agricultural structure[7] is a result of the high cattle density of the southern part compared to the north (Berenz 2003). As a result, in the south 'EHA' are set up on farms, where the manure and agricultural surpluses from the appropriate farm are digested and the electricity and heat are provided to the farm-buildings. Any electricity surplus is then fed into the grid (Janzing 2001a; Janzing 2001b; Muehlstein 2001b; Janzing 2001c; Börnecke 2004; Kuhr 2005). In the north, the 'BGA's are a cooperation of several agricultural or energy supply companies where more than two farmers provide the biomass feedstock (Umbach-Daniel 2002). Farmers and others (organic waste from industry or communities) deliver the biomass to the 'BGA' where the biomass digestion production and utilisation is centralised and the produced electricity is fed into the electricity grid (Umbach-Daniel 2002).

The 'BGA' plants are not included in the analysis since their diffusion and implementation are not as successful as the 'EHA', and the major goal in this paper is to learn from a success story in order to get more insight into the build up of virtuous cycles. For a detailed description of the underlying factors of failure of the 'BGA' a recent study by Umbach-Daniel (2002) can be consulted.

Most of the agricultural biomass digestion plants operate according to the principle of 'wet digestion'[8], where the basic substrates are cow and pig manure; depending on the region also other manure and poultry excrements are digested but in a much lower quantity[9]. In more than 90% of the plants also co-substrates are co-digested, such as energy crops, harvest surplus, verge grass, fat, food residues and local organic household waste, where the added share of co-substrates varies on average between 20-50% (E&M 2002; Berenz 2003). Co-digestion is allowed as long as the criteria's of the 'Biomass Ordinance' are respected. In 2001 the "Ordinance on Generation of Electricity from Biomass"[10] ('Biomass Ordinance') is published by the 'Federal Ministry for the Environment, Nature conservation and Nuclear Safety[11]' that defines which substances fall under biomass, which technologies should be used for the conversion of biomass to electricity and which environmental standards need to be regarded[12] (Janzing 2001b).

6.2 Historical Overview of Biomass Digestion, 1990-2006

In this paragraph, we provide a chronological description of the activities that took place in the biomass digestion trajectory. The description will be subdivided into different periods. The end of each period is chosen on the basis of change in key activities; therefore, not all periods are equal in length. At the end of each period, the sequence of the activities will be analysed on the basis of the System Functions fulfilled and on whether virtuous or vicious cycles occurred. At the end of this paragraph, the key activities per System Function and per time period are summarised in Table 6.3.

6.2.1 From Do-It-Yourself (DIY)-Era to Turnkey Technology, 1990-1997

Between 1980 and 1990, about 15 pilot farm-scale plants (mainly situated in the south) are set up by pioneers. However, hardly any other activities occur (Schultz 2001; Berenz 2003; StMLU 2003).

The activities in the early nineties are driven by the introduction of the *'Electricity Feed Act'*[13] (EFA) for renewable energies and the taxing of fossil fuels[14] (Metzger 1997; Urbach 1997; Berenz 2005). Due to the introduction of these regulations, the expectations among engineers and entrepreneurs that biomass digestion technology could become a promising energy conversion technology for electricity production, increased (F4). In order to realise these expectations, the 'German Biogas Association' (GBA)[15] is founded in 1992 (FachverbandBiogas 2005). The GBA fulfils two important System Functions, i.e. Knowledge Diffusion (F3) and Advocacy Coalition (F7), by bringing together different parties involved in the set-up of biomass digestion projects, putting biomass digestion technology on the political agenda (F7), and supporting the exchange of experience and knowledge in the biomass digestion sectors (F3) (FachverbandBiogas 2005; Schmack 2006). This increasing support of and interest in biomass digestion technology incites the set-up of several other engineering companies in 1995, specialising in the development, planning, and construction of 'ready-to-use' biomass digestion plants, such as Schmack Biogas AG, Farmatic Anlagenbau GmbH, and Biogas Nord (F1)[16] (Koepke 1999; Bach 2003; FachverbandBiogas 2005). The set-up of such companies (F1) helps to change the image of the biomass digestion sector from 'do-it-yourself' and 'eco-fundamentalism' towards a professionalised, turn-key technology in the period 1997-1999 (F6, F7) (Stern 1999). As a result, biomass digestion technology is seen as a serious candidate for sustainable energy production and, as a consequence, several regulations and subsidies were introduced in the following years, stimulating further development and diffusion of biomass digestion technology.

To summarise, the government guides the search by introducing the feed-in tariffs (F4), which triggers the expectations of entrepreneurs (F4), who then carry out research (F2) to provide a professional biomass digestion technology (F1). The positive results, in turn, lead to the set-up of agencies to lobby for the diffusion of biomass digestion technology and its exposure as a renewable energy source (F7). This sequence of events shows that the System Functions interact with each other and trigger further events to occur (see next paragraph).

6.2.2 Liberalisation of the Energy Market, 1998-2000

The following years are characterised by major changes in the institutional environment, i.e. the increase of feed-in rates and the liberalisation of the energy market. The government expected that, by increasing the feed-in rates, energy companies would produce more renewable energies and that, by liberalising the market, the consumer would choose those renewable energies. However, renewable energy sources are still more expensive, 15 cents/kWh compared to 9 cents/kWh, since energy companies provide cheaper energy by the import of nuclear energy (Metzger 1999). Therefore, hardly any consumer made the switch from conventional energy to renewable energy. The electricity company Naturstrom AG had high expectations to recruit about 12000 customers by the end of 1999; however, only about 1200 customers are actually connected (Koch 1999).

The government recognises quickly that the achievement of their goals is jeopardised, and the Federal Ministry of Economics and Technology[17] (BMWi) introduces a 'market stimulation programme for renewable energies[18]' to get back on track (Hell 1999). The aim of this programme is to achieve the goal set by the Federal Government to double the share of renewable energies in the total energy supply until 2010 (Hell 1999). The total budget is 100 million euros, of which, annually, 36 million euros (35% of the total sum, until 2002) are reserved for biomass technologies, where biomass digestion plants could obtain 19k -153k euro depending on their size (Haas 2000).

In spite of the failure of the liberalisation of the energy market to increase the share of renewable energies, the biomass digestion sector continues to grow. With the increase of the 'Electricity Feed Act' rates[19], resulting from persistent lobbying by entrepreneurs (F7), stimulating especially the use of biomass digestion for electricity production (F5), about 150 biomass digestion plants are built in 1998 (F1) and the construction of yet another 150 plants is predicted for 1999 (Bischof 1999; Stern 1999). In spite of the positive growth of the biomass digestion sector, the lobby (F7) for higher feed-in rates for biomass digestion plants continue and the expectations are high (F4) with the introduction of a new regulation in sight.

This period shows that, in spite of the temporary dip of renewable energies, the biomass digestion sector continues to grow due to the higher feed-in rates. The increase of the rates (F4), as a result of the continuous lobby (F7), results in the creation of a market (F5) for electricity production from biomass digestion, as well as an increase of entrepreneurial activities, i.e. 150 additional plants (F1). Again, this shows that the System Functions interact with each other and trigger more activities to develop.

6.2.3 A Boost for Biogas, 2000-2001

The year 2000 is marked by the introduction of one of the most important regulations, the '*Act on granting priority to renewable energies*' also known as the 'Act on Sale of Electricity to the Grid[20]' ('Act') (Janzing 1999b; BMU 2000). This Act replaces the 'Electricity Feed Act' from 1991 and 1998, since the government's goal is to double the share of electricity produced by renewable energies in 2010, which would only be possible if renewable energy producers are guaranteed a fair, long-term remuneration and a reliable basis for investments (F4) (Janzing 1999b). The new rates provide improved perspectives for the agriculture and forestry sector, due to higher rates compared to the previous rate of 7.5 cents/kWh, where no distinction was made with respect to the plant size (F5). In addition, these rates will remain the same for the next 20 years, regardless which government would be in power and with no limit to the amount of electricity to be fed-in (see Table 6.1 for an overview of the rates per plant size compared to the previous

Table 6.1 Overview of rates per size of biomass digestion plant (BMU 2000)

Electricity Feed Act (1991/1998)	**Remunerative arrangement (Act 2000)**	**Installed electrical capacity**
7.5 cents/kWh	10.23 cent/kWh	Up to 500 kW
	9.21 cent/kWh	Up to 5 MW
	8.70 cent/kWh	5-20 MW
		From 1 January 2002 onward, the remuneration would be reduced by 1% for each newly built plant

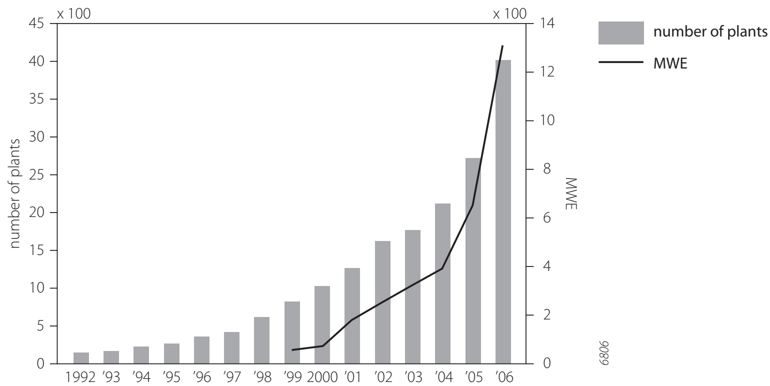

Figure 6.1 Installed capacity of biomass digestion plants in Germany (FachverbandBiogas 2005)

rate) (Solarenergie-Foerderverein 1999; Haas 2000; Janzing 2000a). Again, lobby activities (F7) in previous years turned out to be successful obtaining higher rates and long-term security.

Dr. Gerhard Rech, head of Department of Renewable Raw Materials and Energy of the 'Federal Ministry for Food, Agriculture, and Forestry' (BML)[21], expects the feed-in of electricity from the agricultural sector to double, as a result of the new remuneration rates (F5) (Haas 2000). As additional support, the BML ensures farmers they could cultivate energy crops on 'fallow land' without losing the subsidy for keeping the land fallow (Haas 2000).

The expected boost in the biomass digestion sector is observed shortly after. In 2000, about 200 plants are set up, in 2001, so are another 200 and, in 2004, yet another 400 are built, resulting in a total of 1650 plants with a capacity of 250 MW in 2002 (see Figure 6.1: Installed capacity of biomass digestion plants in Germany), showing a positive development of the diffusion of biomass digestion technology. (FachverbandBiogas 2005)

Nonetheless, there are still uncertainties about the availability of biomass and waste streams, and their classification and definition, which leads to more lobbying asking for more security and clarity (F7) (Preuss 2001a; Janzing 2002). These demands are fulfilled when the '*Ordinance on Generation of Electricity from Biomass*' ('Ordinance')[22] (F4) is introduced. The Ordinance defines which substances fall under biomass, which technologies are to be used for the conversion of biomass to electricity, and which environmental standards have to be complied with (Janzing 2001b). In order to ensure the flawlessness of the Ordinance, a scientific monitoring of two and a half years is carried out, where different biomass streams will be assessed (BMU 2000; E&M 2002). The combination of the Act and the Ordinance form the very basis of an increasing expansion of electricity production from biomass digestion in Germany, with the expected set-up of another 600 biomass digestion plants with a total capacity of 75MW between 2001 and 2002 (Kueffner 2001). Given these positive expectations, Da Costa Gomez, managing director of the GBA, estimates:

> "…biomass digestion technology to cover up to 11% of the electricity supply in Germany […] and […] biomass digestion production to be a second income and employment pillar for farmers, since the profits of biomass digestion plants are guaranteed for the next 20 years, due to the improved remuneration rates and guaranteed stability of 20 years; in addition, the image of the agricultural sector would be improved if farmers were looked upon as energy providers." (Schultz 2001)

In this period, the lobby activities (F7) are, once again, successful to realise favourable conditions for the biomass digestion sector. This results in the creation of a market (F5) for farmers using biomass digestion technology, due to the increased feed-in rates and the maintenance of the subsidy for fallow land (F4). This results in a drastic increase of plants being set up (F1) (cycle A). In addition, more physical resources (F6) are provided with the introduction of the Ordinance, allowing co-digestion, once again a result of lobby activities (F7).

6.2.4 The Reverse of the Medal, 2002-2003

At this moment in time, everything seems to be going well for the biomass digestion sector. The technology is seen as a profitable renewable energy technology and the institutional conditions (higher feed-in rates of the EEG) are aligned with the needs of the entrepreneurs.

However, in 2002, without further explanation, Minister Müller of the BMWi announces a cut back from 150 million euros to 86 million euros of the investment support for biomass digestion plants within the 'Market Stimulation Programme' (-F6) (Schultz 2001). As a result, the construction of plants under 200 kW is economically unprofitable and several farmers stop their initiatives (-F1) (Schultz 2001; Muehlstein 2001a). This reduction of financial resources (-F6), causing the non-profitability of small- and middle-sized biomass digestion plants using only 'natural' biomass[23] (-F1) (Pecka 2003e), results in a decreased growth of the biomass digestion sector. In the first half of 2003, only 30 plants are set up, instead of the 75 of the previous year (Pecka 2003e). Furthermore, many projects are now on hold and entrepreneurs cannot set up any new projects, as argued by the vice-president of the GBA, Markus Ott:

> "…another 200 projects are ready to be set up but are on hold, waiting for a clear sign from Berlin. In the current situation, entrepreneurs of biomass digestion plants can only do as much as retrofitting or expansion work…" (Pecka 2003e)

In an attempt to increase entrepreneurial activities, the Green Party[24] starts an initiative (F4) to better inform farmers about the advantages and profits of biomass digestion. Furthermore, a support programme for biomass digestion plants[25] is set up (F7) (Köpke 2001a; E&M 2002; Gruber 2005). Additionally, to compensate for the previous cut down on research money in the Market Stimulation Programme, the 'Bundeshauptausschuss' agrees to increase the budget[26] for the programme from 150 million euros to 200 million euros for 2002 (F6) (Muehlstein 2001a).

To summarise, the cut back of the budget (-F4) triggered several negative activities, such as the discontinuation of projects (-F1) and the reduction of financial resources (-F6), triggering the beginning of a vicious cycle. However, due to the lobby (F7) and fast action of the

'Bundeshauptausschuss' (F4), the worst has been avoided, due to powerful lobbying (F7) resulting in new financial resources (F6) for projects to continue (F1).

6.2.5 The Breakthrough, 2004-2006

In 2003, the preparations for the amendment of the Act under the leadership of Jürgen Trittin, Minister for Environment, start to develop, due to continuous lobbying (F7) for better conditions for the biomass digestion sector (F4). The Green Party organises a conference to give all interested parties the opportunity to influence the amendment (F4) (Gammelin 2003). Aim of the conference is to counter the opponents of renewable energies with constructive work, instead of getting caught up in polemics (F7) (Gammelin 2003). Following this conference, the Federal Ministry for the Environment (BMU) accepts the concept for the amendment of the Act by the GBA (F4) (Pecka 2003e). This concept is in agreement with the requests of the Federal Bioenergy Union[27] and the German Farmers Union[28], where the following amendments are proposed:

> "Rates higher than 10 cents/kWh; additional compensation of 2.5 cents/kWh for the use of 'traditional' products for plants with an electrical capacity; compensation of 12,5 cent/kWh for plants of 75 kW and 11.5 cents/kWh for 200 kW plants; facilitation of the complicated and lengthy permit regulations, since many regulations[29] contradict each other, resulting in the delayed set up of biomass digestion plants" (Pecka 2003e)

Finally, on 1 August 2004, the *amendment of the Act* enters into force, with the aim:

> "… to facilitate a sustainable development of energy supply, particularly for the sake of protecting our climate, nature, and the environment, to reduce the costs of energy supply to the national economy … and … to contribute to the increase in the percentage of renewable energy sources in power supply to at least 12.5% by 2010 and to at least 20% by 2020." (BMU 2004)

The new version of the Act provides additional fees (bonuses) that could be used cumulatively, if the electricity is produced exclusively from self-regenerating raw materials[30], combined heat-power, or if the biomass is converted using innovative technologies (e.g. thermal chemical gasification, fuel cells, gas turbines, etc.) (BMU 2004). Table 6.2 provides an overview of the old and new fees for electricity produced by plants with a capacity up to and including 20MW, exclusively using biomass:

The most satisfactory change is the increased bonus from 2.5 to 6 cents/kWh for plants up to 500 kW, using self-regenerating raw materials as requested by the GBA, the Federal Bioenergy Union and the German Farmers Union in 2002 (Pecka 2004b). In addition, a bonus of 4 cent/kWh will be given to plants up to 5 MW when using raw materials[31] (Pecka 2004b). The expectations are very high due to improved rates. For 2004, the construction of another 500 plants, each with an average capacity of 330 kW, is expected (Pecka 2004b). Dr. Da Costa Gomes, GBA even expects that:

> "…the demand for biomass digestion installations would be higher than the capacity of construction companies…" (Pecka 2004b; Pecka 2005a)

Table 6.2 Overview of Old and New Fees of the Act

Installation capacity	Electricity Feed Act (1991/1998)	Fee paid (ct/kWh) (EEG 2000)	Bonus for using renewable raw materials (EEG 2000)	Fee paid (ct/kWh) (EEG 2004)	Bonus for using renewable raw materials (EEG 2004)
Up to 150 kW				11.50	
50 – 500 kW		10.23	2.50	9.90	6.00
500kW – 5 MW		9.21		8.90	4.00
5 – 20 MW		8.70		8.40	
KWK-bonus (FNR 2005)	7.5 cents/kWh			2.00	
Technology-Bonus[1] (FNR 2005)				2.00	

As of 1 January 2002, the remuneration will be reduced by 1% for each newly built plant (EEG 2000).
From the amended Act, the new digression rate will change from 1% to 1.5% (EEG 2004).

1 A supplementary payment of 2 cents/kWh is added when innovative technologies are used, such as fuel cells, gas turbines, ORC (organic Rankine cycle) installations (in particular Kalina cycle or Stirling motors).

Once again, the expectations are fulfilled with the set up of another 600 plants, bringing the total number of plants in 2005 to 2700 with a total capacity of 650 MW (Keck 2004; Pecka 2005a). The managing director of GBA, Dr. Da Costa Gomez, expects that, from now on, energy companies would invest in biomass digestion plants as well, due to the improved conditions, such as the higher rates and facilitated conditions for feed-in, transfer, and distribution of electricity due to the amendment of the Act (F4) (Shafy 2004; Pecka 2005a). Furthermore, the EU Commission confirms the success of the amended Act, since it turns out to be the most efficient and convenient method to support the development and diffusion of renewable energies, as confirmed by the high growth of biomass digestion plants (Pressedienst 2005).

In this period, the trigger for the long-awaited breakthrough of biomass digestion is provided by the introduction of the amendment of the Act (F4). Due to the higher and differentiated rates, the share of electricity produced from biomass digestion on the market (F5) was reinforced, resulting in a significant increase number of plants constructed (F1).

6.2.6 The Functional Analysis of Biomass Digestion Technology in Germany, 1990-2006

Throughout this period, several key activities triggered the fulfilment of System Functions. In the 90s, the need for sustainable energy conversion technologies leads the government to implement a feed-in law to stimulate the production of renewable energy (F4). This triggers agencies to lobby for biomass digestion technology (F7) and for engineering companies to develop a turn-key technology (F1). Successful outcomes with respect to the professionalisation of the technology (F2), lead to lobbying (F7) in order to request the improvement of the feed-in rates (F5) as to better stimulate the development of biomass digestion technology and electricity production (F2). As the rates are altered (F4), the expectations of biomass digestion technology increase (F4), positive knowledge is obtained and diffused (F2, F3), stimulating more entrepreneurs to set up biomass digestion plants, mainly on farms (F1). In this case, a niche market for biomass digestion technology is created in the agricultural sector (F5). Again, positive results from this application increase the enthusiasm and trust of actors in the field (F7) and more plants are set up (F1). In addition, the lobby activities continue (F7) and the feed-in rates are amended (F4). In the meantime, abundant resources through research programmes (F6) are allocated to the technology as to ensure its development. Finally, favourable institutional conditions such as the Act, the Biomass Ordinance (F4) and research programmes (F6) ensure a steady growth of biomass digestion plants, expected to continue in the future (F1). This sequence of positive activities shows that the System Functions reinforce and interact with each other, thus building up a virtuous cycle, which continues to grow throughout the years, in spite of a temporary dip caused by research budgets being cut back.

6.3 Case Comparison between the Dutch and German Biomass Digestion Innovation System

In this paragraph, the German and Dutch biomass digestion case will be compared on the basis of the System Functions fulfilment. The Dutch case has been analysed thoroughly in Chapter 5 of this thesis by using the same theoretical approach and methodology, as to allow a systematic comparison with the German case. For clarity reasons the comparison will be divided into several time periods that have also been used previously in the historical descriptions.

The tables below (6.3a and 6.3b) give an overview of the key activities in the Netherlands and Germany for two time periods. The data is based on the previous narratives of Germany and of the Netherlands. For simplification and clarity reasons the tables have been split per time periods 1988-1995 Table 6.3a for Germany and the Netherlands and 1998-2004 Table 6.3b Germany and for the Netherlands.

1980-1990: The Pioneers' Era

In both countries, pioneers develop entrepreneurial activities (F1) by setting up pilot plants in the 80s. Knowledge is created through experimentation (F2). However, in the Netherlands, surveys on the status of the existing plants are disappointing, as technical problems are not solved and unfavourable regulations delay the set up of plants, making most of the projects unprofitable (-F1). In Germany, the expectations of and trust in the potential of the technology are high and lobby activities for technological development and better institutional conditions take place (F4, F7). In addition, the technology is further developed and becomes available as turn-key technology (F1). This technological development is lacking in the Netherlands. The technology remains unreliable and expensive, which influences financial support negatively, so that no tax exemption, or subsidy for biomass digestion are provided. Because of this, System Functions such as Guidance of the Search (-F4), Market Formation (-F5) and Resource Allocation (-F6) are not fulfilled. As a consequence, the remaining System Functions are not fulfilled either and no virtuous cycle is started.

In this period, the most important system failures in the Netherlands are the lack of guidance and lobbying to justify the research on biomass digestion. In Germany, entrepreneurs lobby to include biomass digestion as renewable energy technology and develop it as a turn-key technology, whereas in the Netherlands, technical problems remain unsolved, resulting in the reluctance of investors, entrepreneurs and the government to support it.

Table 6.3a Comparison of key activities in the Netherlands 1988-1995 compared to key activities in Germany 1990-1997

System Functions	The Netherlands Period 1988-1995		Germany Period 1990-1997
	Positive	**Negative**	
F1: Entrepreneurial Activity	5 plants Deersum, Helmond, Lelystad, Tilburg, Breda	2 plants shut down Deersum, Helmond	Develop turn-key technology
F2: Knowledge Creation		Technical problems still not solved	Research on biomass digestion
F3: Knowledge Diffusion			Positive findings diffused
F4: Guidance of the Search	EWAB programme; BOOM decree	No more support digestion by Min of Agriculture	Government recognises digestion as renewable energy
F5: Market Formation			Government introduces feed-in law
F6: Resource Allocation		Cut back of 81 million euros research budget;	
F7: Advocacy Coalition	Lobby for digestion as renewable energy technology and support for farmers to co-digest		Entrepreneurs and Unions lobby for biomass digestion as renewable energy and feed-in law

1990-1998: Renewable Energy Conversion Technology

In Germany, in the 90s, the awareness of climate change and the need for renewable energy sources acknowledges biomass digestion as a potential candidate to contribute to sustainable energy supply (F4). In the Netherlands, this same environmental awareness and need for renewable energy conversion technologies did exist. However, biomass digestion technology is not identified as an energy conversion technology (-F4). The Netherlands struggles with a waste surplus problem. Biomass digestion is considered a potential option to help reduce the waste problem and manure surplus, as it is mainly used on farms to digest manure and, as such, not perceived as an energy conversion technology (-F4). The consequence of this different perception is that the Dutch government has little trust in and low expectations of the potential of the technology as a sustainable energy technology (-F4). In addition, less financial support is provided (-F6) and no lobby activities occurred (-F7). This, in turn, leads to a lack of market formation (-F5). In contrast, the German actors have high expectations of biomass digestion technology as an energy conversion technology, which triggers further lobbying for adequate regulations (F7), more financial support for the development of the technology (F6), and the formation of a market by providing higher feed-in rates (F5) enabling the technology to compete with conventional energy technologies. The end result of this virtuous cycle is a strong increase in the number of biomass digestion plants (F1).

In the Netherlands, the main system failure in this period, is caused by, once again, the lack of guidance and lobby activities. The Dutch government does not provide any coherent strategies or visions as to encourage actors to further develop biomass digestion as a renewable energy technology. On the other hand, there are no actors lobbying for it, because of which the

Table 6.3b Comparison of key activities in the Netherlands 1995-2004 compared to key activities in Germany 1998-2004

System Functions	The Netherlands Period 1995-2004		Germany Period 1998-2004	
	Positive	**Negative**	**Negative**	**Positive**
Function 1: Entrepreneurial Activities	1 plant constructed Groningen; 3 demo plants Nij Bosma, Sterksel, De Marke	3 plants shut down Lelystad, Tilburg, Breda	Stagnation of construction	2700 plants
Function 2: Knowledge Development				
Function 3: Knowledge Diffusion				
Function 4: Guidance of the Search	2004: List for co-digestion	2002: Delay and uncertainty about MEP regulation	Cut back of research budget	High expectations for biomass digestion as renewable energy; 2000: Introduction of the Act, higher and differentiated rates; 2001: Ordinance, defines biomass and allows co-digestion; 2004: Amendement of the Act
Function 5: Market Formation	9.7 eurocents/kWh by MEP for 10 years			Higher feed-in rates make it more profitable 8.40-11.50 eurocents/kWh
Function 6: Resource allocation			Lack of financial resources	Market stimulation programme for renewable energies
Function 7: Advocacy Coalition	Lobby for digestion as renewable energy technology as to obtain long-term exemption from taxes			Lobby for higher and more differentiated feed-in rates
Exogenous Factors	Liberalisation of the energy market			

government still does not recognise it as a renewable energy technology. In Germany, however, the actors are strongly lobbying for the technology. They manage to obtain high and specific feed-in rates for biomass digestion. This leads to more investors and entrepreneurs becoming enthusiastic about the technology and to more plants being constructed.

2000-2004: Institutional Alignment
In addition to the professionalisation (i.e. provision of a turn-key technology) (F2), the biomass digestion sector in Germany is very well organised by setting up Unions and Associations (F7). The lobby activities of those latter turn out to be strong enough to put biomass digestion on the political agenda, so that favourable and adequate regulations are introduced, further stimulating the set up of biomass digestion plants (F1). Examples are the Market Stimulation Programme in 1999, the Ordinance in 2001, and the Act in 2000 plus its amendment in 2004 (F4). In addition supple regulations (F4) exist for co-digestion that allow the addition of organic substances to manure, resulting in a higher biogas output. This series of regulations provides a stable and secure framework for biomass digestion technology to 'survive' the liberalisation of the energy market (F5), to attract more investments (F6), and to increase the trust of entrepreneurs (F7). As a consequence, the number of plants constructed increases considerably (F1).

In the Netherlands, hardly any series of regulations or joined strategies is developed (-F4), and once the energy market is liberalised, biomass digestion is left on its own devices to compete on the market (-F4). Nonetheless, some pioneers and entrepreneurs continued their efforts and finally in 2004, after several years of lobbying, a list of products is published allowing co-digestion. In addition, also a feed-in tariff system is introduced where remuneration rates (9.7 eurocents/kWh) are provided for the electricity production of biomass digestion. The diffusion that occurred in Germany from 1998 onwards is expected to kick off in the Netherlands after 2004[32].

6.4 Conclusion

The research question of this paper is: *How can we explain the high diffusion of biomass digestion technology in Germany and which lessons can be drawn for the Netherlands from German experiences?*

First, to start with an answer to the first part of the research question, the dynamic analysis of the functioning of the German biomass digestion Innovation System shows that a positive functional pattern took place. All System Functions show a continuous build-up over the years. As a result, the system gains enough critical mass to overcome technical problems and institutional changes, such as the liberalisation of the energy market. Furthermore, as the System Functions interact with each other, they reinforce each other and incite other System Functions to be fulfilled as well. More specifically, the System Functions that propel the technology from a development phase to a diffusion phase are the entrepreneurial activities to improve the technology and the lobbying that put the technology on the political agenda as to receive more institutional and financial support. As a result, several favourable regulations are introduced, inciting entrepreneurs to construct more plants. This results in the formation of a market, which, in turn, draws the interest and trust of investors to support that particular technology, leading to the construction of a large amount of digestion plants (about 2700 plants in 2006).

This case shows that technology development is successful when the System Functions are fulfilled, reinforcing each other. However, some critics may say that the case of Germany is a big subsidy story, where the success is attributed to the large amounts of money provided by the government, rather then the System Functions fulfilment. Yet, our analysis clearly shows that the money and the institutional alignment were not in place beforehand or fell out of the sky, but that due to the build up of System Functions such as Entrepreneurial Activities and Advocacy Coalitions that provided a reliable technology and lobbied for better institutional conditions and financial resources, the alignment occurred gradually over several years. Thus, this shows that the build up of a well functioning Innovation System around a technology plays a crucial part for its successful diffusion, as well as favourable technical and economic aspects.

Which lessons can be learned in the Netherlands from German experiences?
In the case of biomass digestion in the Netherlands, none of the System Functions show a continuous build-up over the years. Technical problems are unsolved and there are no consistent lobby activities to counter and improve the unstable and unfavourable institutional environment. This results in the lack of guidance of the search for biomass digestion. No financial means are obtained, and hardly any entrepreneurial activities are undertaken.

In the Netherlands, the starting point to increase the share of renewable energies is the same as in Germany. However, the main barrier in the Netherlands is the inconsistent and complicated policy of the Dutch Government, where no long-term strategy is provided and no security ensured, i.e. biomass digestion is not seen as a renewable energy option and strict regulations forbid co-digestion. Therefore, a first requirement is the commitment of the government to provide a stable and coherent policy. However, as mentioned above, the technical and economic aspects of the technology are important as well. In Germany, the removal of technical problems increased the enthusiasm and support of this technology, so that lobby activities for financial and institutional support were fulfilled. Thus, in the Dutch case, to ensure government support, entrepreneurs should have removed the technical problems by exchanging knowledge with each other and foreign actors as to learn from each other's experiences. Thus, instead of working in isolation, entrepreneurs should have packed together to emphasise their cause. Simultaneously however, the government should have been forthcoming as well by allowing trial and error periods and by not dismissing all efforts immediately after the first failure. Additionally, they should have provided consistent policies such as feed-in rates, as to create a niche market for the technology to develop in a protected space. A build-up of System Functions would then be expected to occur, as in the case of Germany, where System Functions reinforce each other and set off virtuous cycles, resulting in the successful diffusion and implementation of biomass digestion technology.

Notes

1 Conference paper presented at EASST 2006, SPRU 2006 and International Expert Workshop Utrecht 2006; A Paper version based on this chapter has been submitted to the International Research Journal of Technology Analysis & Strategic Management.

2 The Federal Government's goal is to increase renewable energy sources (RES) share in overall energy supply to at least 4.2% by 2010. In 2005, renewable energies' share in primary energy consumption was 4.6%, which means that the target has already been achieved (BMU 2006b). The greatest contribution came at about 67% from bioenergy sources such as wood, biogas and bio-diesel (BMU 2006b).

3 The Dutch case has been analysed in a previous study with the same theoretical framework and methodology, as to enable systematic comparison with the German case. For further detail on the Dutch case see Chapter 5 or (Negro et al. 2007)
4 In German: Einzelhofanlagen (EHA)
5 In German: Biogasgemeinschaftsanlagen, (BGA)
6 In German: Länder
7 In German: Agrarstruktur
8 In German: Nassvergärung
9 Biomass digestion is only profitable with 80-100 'cattle units' (in German: Grossvieheinheiten), 100 cows can cover the energy need of 30 average households where each cattle unit produces about 1.5 m^3 biogas (Janzing, B. 2000; FAZ 2003)
10 In German: Biomasse Verordnung (BiomasseV)
11 In German: Bundesministerium fuer Umwelt, Naturschutz und Reactor Sicherheit (BMU)
12 In the Netherlands co-digestion is not allowed until 2004 when finally a 'green list' with biomass substrates is published that allows co-digestion of some kinds of biomass substrates with manure (Didde, R 2004; Zoethout 2004; Stromen 2004a; Stromen 2004b) (see for a full account (Negro et al. 2007))
13 In German: Energie-/Stromeinspeisegesetz (BGBI I S.2633) (passed on 7 December 1990, predecessor of the 'Act on granting priority to renewable energies' introduced in 2000). Public electricity utilities are obliged to feed electricity produced by renewable energies into the grid and to compensate 80% of the average profit per kWh of the electricity produced by biomass (Urbach 1997).
14 In German: Mineralölsteuergesetz, (MinöStG) (BGBI S. S. 2150, 2185) passed on 21 December 1992
15 In German: Fachverband Biogas e.V (www.biogas.org)
16 See Table 5 in the Appendix for more relevant actors/organisations within the German biogas sector
17 In German: Bundesministeriums fuer Wirtschaft und Technologie (BMWi)
18 In German: Marktanreizprogramm zu Gunsten erneuerbarer Energien
19 The Feed-in Act (StrEG) is altered on 24 April 1998 by article 3 Nr 2 (BGBI 1 S. 730/734). Electricity produced by biomass and geothermal are compensated with 8.25 – 8.75 cents/kWh (16.5 – 17.5 Pf/kWh) (Metzger 1997; Solarenergie-Förderverein 1999) Nb: Conversion rate: 1 DEM = 0.511292 EUR; 1 EUR = 1.95583 DEM (http://www.xe.com/ucc/convert.cgi; 2006.02.20 10:09:29 UTC)
20 In German: Gesetz fuer den Vorrang Erneuerbarer Energien, EEG, passed on 17 March 2000 by the Bundestag
21 With the organisational decree of the Federal Chancellor from 22 January 2001, the Federal Ministry for Food, Agriculture, and Forestry (BML) was transformed into the Federal Ministry of Consumer Protection, Food, and Agriculture (BMVEL)
22 In German: BiomasseVerordnung (BiomasseV), passed on 21 June 2001 by the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU), acting in agreement with the Federal Ministries for Consumer Protection, Food, and Agriculture and for Economics and Technology, and respecting the rights of the German Bundestag.
23 In German: Naturbelassen, untreated biomass, i.e. agricultural surplus, energy crops, verge grass, manure. A higher energy yield is obtained when frying fat or other products from the food industry are co-digested.
24 In German: Bundestagsfraktion Buendnis 90/Die Grünen
24 In German: 'Rationelle Energieverwendung und Nutzung unerschöpflicher Energiequellen' (REN-Programm). Aim is to accelerate the market introduction rate of emerging technologies, including biomass and biogas plants (Gruber 2005)
26 In German: Haushaltansatz

27 In German: Bundesverband Bioenergie, BEE

28 In German: Deutschen Bauernverband, DBV

29 Such as federal emission regulations, construction rights, increasing security requirements, organic waste regulations, waste laws, EU-hygiene guidelines, fertiliser laws, and different state operations (Pecka 2003e)

30 In German: Nachwachsende Rohstoffe (NawaRos)

31 In addition to the renewable raw material bonus, an incentive for the use of the produced heat and innovative technologies, i.e. 2 cent/kWh per new plant, is available. The CHP bonus is only available for electricity production, corresponding to the requirements of the 'CHP-modernisation law'. The technology bonus would provide less impulses, even though some operators did profit from it. Nonetheless, in this respect, the upgrading of biogas to natural gas quality could be favoured, which would stimulate the feed-in of biogas into the gas grid. However, a gas feed-in law is still out of sight in Germany (Pecka 2004b), at least until 2006, when the Green Party would launch another attempt to propose a 'Feed-in Law for Biogas' (Einspeisegesetz für Biogas) along the lines of the 'Feed-in Act for Electricity' (Gammelin 2006).

32 However, these positive expectations have been shattered recently (August 2006) by the Dutch Minister of Economic Affairs, who directly stopped any further subsidies within the MEP-framework for renewable energies, for he believes that the targets for renewable energies in 2010 will be reached with the currently installed capacity. With this measure, biomass projects worth about half a billion euros and 100MW capacity are also stopped immediately (Blijker 2006; Brugh 2006; Handelsblad 2006; Havermans 2006; Uffelen 2006; Volkskrant 2006)

7 Biomass gasification in the Netherlands from 1980-2004[1]

7.1 Introduction

In this chapter we analyse the development and diffusion of biomass gasification technology. The reason for this choice is that gasification technology is generally considered to be a considerably promising technology to convert biomass into useful products. First, the conversion efficiency of biomass into electricity is much higher than for biomass combustion and digestion. Second, by means of gasification, biomass can – apart from electricity – also be converted into feedstock for the chemical industry and for the production of liquid biofuels. Logically, the expectations around this technology are quite high and many actors see it as *the* technology to achieve a breakthrough for biomass as modern energy source. However, despite the high expectations, high efficiency, and wide range of applications, biomass gasification has not been successfully developed, diffused, and implemented in the Netherlands so far. The research question therefore is:

What are the inducement and blocking mechanisms that have determined the evolution of biomass gasification in the Netherlands?

By analysing the Innovation System for biomass gasification in the Netherlands the inducement and blocking mechanisms are identified, which show that a structural misalignment occurred between the institutional framework within which the technology developed, on the one hand, and the technical requirements on the other. The lack of System Functions such as guidance of the search, resource allocation and advocacy coalition explain the failure of this technology.

7.1.1 Notes on Methodology and technical aspects

The same theory and methodology as described in chapter 2 and 3 are applied to this case study. In the historical analysis the key processes, more in particular the (lack of) virtuous and vicious cycles that took place within the biomass energy Innovation System are highlighted. The symbols F1 – F7 refer to the seven System Functions as described in Chapter 2.4. The historical event analysis was partly validated by interviews with various actors in the field[2].

For this case study the focus lies on biomass gasification plants where only biomass is gasified; combined gasification of coal and biomass is not included, since in combined gasification coal is the major feedstock used and the biomass share is only marginal, resulting in other technical properties than full biomass gasification (Didde 2001). We are aware of the experimentation of coal and biomass co-gasification in the large-scale (205 MW) coal gasification plant called 'Buggenum', but due to the above mentioned reason we will not include the trajectory of this project (Aarder 2000; Didde 2000; Postma/Corr 2000). In addition we focus on the use of biomass gasification for electricity production. Biomass gasification as for the production of transportation fuels (e.g. Fischer-Tropsch fuels) is developed in quite a different innovation system. Therefore, it is not analysed in detail but briefly sketched in order to illustrate the dependencies between both innovation systems.

7.2 Historical Overview of Biomass Gasification from 1980-2004

7.2.1 The Hype of Biomass Gasification, 1990-1998

In the early 90's biomass gasification starts to get attention in the Netherlands. In the previous period, the Dutch government mainly stimulates research on alternative energy sources by publishing formal policy documents (1982 – White Paper on Renewable Energy; 1989 – National Environmental Plan (NMP); 1990 – White Paper on Energy Saving). However, these official documents are not backed up by other policy initiatives, which results in low funds for research on renewable energy; the engagement of implementation remains on general terms and on a voluntary basis (NE&S 1982a; Blok 1985a; Verbong et al. 2001).

At the beginning of the 1990s, two urgent problems are identified. The Netherlands lack sufficient landfill space for waste disposal, resulting in several knowledge development programmes set up by Novem[3], to reduce the amount of final waste by converting waste into useful energy (1989 – EWA programme; 1990 – NOH programme, 1992 – EWAB programme) (DE 1992e-a). In addition, the awareness of the negative consequences of using fossil fuels increases, causing the need to develop and implement alternative energy conversion technologies to become more urgent (Lysen et al. 1992a). These two problems guide the search towards new technologies that could solve these problems (F4) and create legitimacy for new development paths (F7).

The idea for large-scale biomass gasification is until now still rooted in Dutch research on coal gasification and development activities of small-scale biomass gasification units for developing countries. However, positive results obtained abroad incite the idea to use biomass gasification as an alternative conversion technology for waste surplus in the Netherlands (F2) (Carpentieri et al. 1993; Williams and Larson 1993). In addition, the province of North-Holland[4] develops policies to provide a clean, sustainable and affordable energy supply by combining wind energy and biomass gasification (F4) (see the next paragraph for a detailed description of the North-Holland project) (Daey Ouwens 2005a). This triggers the commission of an inventory study for gasification of wet biomass waste-streams for electricity production, where it is found that these biomass streams can also be used for gasification and that they reduce costs due to their negative value (Faaij et al. 1992). In addition a study trip to biomass gasification projects in Sweden[5,6]and Finland[7] is organised by the Dutch 'Biomass Technology Group (BTG)', to obtain more knowledge about the high potential of biomass gasification technology and the possibility to set up such plants in the Netherlands (MilieuTechnologie 1993a; Kwant and Knoef 2004b). During the same period, Novem publishes a report that demonstrates that biomass gasification of energy crops like poplar and miscanthus for electricity production can also be quite profitable, which has put biomass gasification on the political agenda. The report states that electricity production is preferred to biofuels' production from conventional agricultural crops (Lysen et al. 1992a). This report has a major impact and shifts the current guidance of the search away from the use of biomass for automotive fuels towards the use of biomass for electricity by means of gasification (F4). This report triggers more research; desktop studies show that biomass gasification has a higher energy efficiency than biomass combustion (37-40% vs 25-30%) and that production costs can be reduced by using biomass waste streams instead of energy crops (Faaij et al. 1992; DE 1992a; DE 1992b; Doorn 1992b; DE 1992c; Doorn 1992d) (F2). Due to these positive characteristics, the sustainable energy sector expresses high expectations of biomass gasification (DE 1993a; DE 1994b; MilieuTechnologie 1994b; Venendaal and Stassen 1994) (F4). In addition the EU 'Thermie' programme[8] is started and several projects receive financial support from it (e.g. Zeltweg, Austria; Lathi, Finland; Amer-plant, The Netherlands; Arbre-project, UK) (Morris et al. 2005). Also, Shell shows interest and invests in a biomass gasification project in Brazil; however the project is not realised (Carpentieri et al. 1993). As a result, and in a very short time, biomass gasification is considered to be equally useful as other competing renewable energy technologies, as the following quote shows:

> "The contribution of biomass to the energy supply is gaining more and more importance. The most realistic routes that can be used for the production of electricity are either gasification or co-combustion of biomass in existing installations (EPON-project), combined-heat-and-power (CHP) application and the conversion of biomass into biogas." (DE 1993b)

The high expectations of biomass gasification in this period are also reflected in the short development time that is expected for commercialisation of the technology, and in the plans to invest in technology development. Braber et al (1993) state the following:

> "In the coming years, more emphasis will be put on gasification, since this technology has the potential to be cost-effective and to convert waste and biomass with a high energy efficiency. Lots of efforts are expected to be necessary to achieve these expectations, since in 2000 it will be evaluated whether gasification can be implemented on a large scale." (Braber et al. 1993)

Knowledge development indeed picks up. Studies are carried out (F2), which show that wet biomass (organic waste, sludge etc.), only thought to be suitable for digestion or fermentation, can also be used for gasification, providing additional biomass resources for gasification and higher energy output than for digestion (Doorn 1992d; MilieuTechnologie 1993) (F6). In addition, technological problems are not considered to be a major obstacle, as the next fragment shows:

> "The gasification of organic household waste is researched by the Department of Science, Technology and Society at Utrecht University. Since no compost is being produced during gasification and due to its lower conversion costs, this conversion system has chances to become a realistic option. The practical problems, cleaning the syn-gas from alkali- and heavy metals, do not form any unsolvable problems." (DE 1992b)

These expectations result in a specific research programme, the 'National Biomass Gasification Research Programme[9]' by Novem, aiming to demonstrate biomass gasification technology in a number of projects. These projects not only lead to knowledge development (F2) and more financial resources (F6), but also guide the search by highlighting the importance of this technology (F4). The aim of the programme is the following:

> "Special emphasis will be put on the set up of a circulating fluidized bed gasifier for the gasification of biomass waste. The aim is to demonstrate the techno-economic feasibility and to provide long-term perspectives for this technology on the large-scale conversion of waste and biomass." (Braber et al. 1993)

To recapitulate, positive results from abroad and a high impact study (Novem) puts biomass gasification on the agenda and quickly results in the rise of expectations for biomass gasification in the early 90's. This, in turn, triggers a series of activities that can be classified as Knowledge Development, Guidance of the Search, and Mobilisation of Resources. The rise of a virtuous cycle is observed, since positive results from research (F2) result in high expectations of biomass gasification (F4), which, in turn, result in the set up of research programmes in the context of which demonstration projects are set up (F2, F6).

However, not all System Functions in the Biomass Gasification Innovation System receive attention in that first period. In addition, there are several critical voices that warn against following the hype without first solving technical problems and obtaining consistent support from the government. One of the leading figures in this field expresses it as follows:

> "There is no clear-cut national programme about biomass in the Netherlands. Some projects are being prepared, but mainly for the co-combustion of biomass in coal plants" (Daey Ouwens 1993)

An additional problem is the lack of market formation (F5) by the Dutch government. To attract more research funds (F6) and to get entrepreneurs interested (F1), a clear vision of the future market for these types of technologies is necessary. At this time, there are no subsidies, feed-in tariffs, or launching customer activities of the government. A spokesperson from an energy distribution company states the following:

> "There are possibilities to set up gasification plants in the Netherlands, since there is enough hay and verge grass that could be used as short-term options. However, who is going to pay for it? (E&MSpectrum 1993a)

Finally, there are some critical voices that warn against rushing the set up of large-scale plants (due to high expectations and promises (F4) and ignoring technical problems), as long as the technology has not been proven, as expressed by Mr Smakman, project leader of the EWAB programme (E&MSpectrum 1993a; E&MSpectrum 1993e).

> "… A long-term development is needed before gasification will be established in the Netherlands and the future of gasification is difficult to predict, since there is no experience and expertise in the Netherlands for this technology. Additionally, practice is unmanageable, so the new technology has to be 'proven' first, before it will be accepted." (E&MSpectrum 1993a)

In this period, two projects aiming to realise large-scale application of biomass gasification dominate the dynamics of the Biomass Gasification Innovation System. Both projects receive much attention in the Dutch energy system and they trigger many other processes in the Innovation System, as we will see in the following paragraphs.

7.2.2 The Ups and Downs of the North-Holland Project, 1993-1998

In 1993, the Province of North-Holland, the coordinator of the national energy companies, SEP[10], several energy companies, UNA and PEN, and researchers from ECN[11] design plans for the first large-scale gasification project in the Netherlands (F1, Entrepreneurial Activity) (DE 1994e; DE 1995c; E&MSpectrum 1995c). Several feasibility studies are carried out over the years to assess the location, scale, and biomass streams (E&MSpectrum 1993b; DE 1994a; DE 1995a; E&MSpectrum 1995a; E&MSpectrum 1995c) (F2, Knowledge Creation). At the end of 1994, the pre-studies are completed and the decision is taken to gasify waste wood, thinning and other residues in a 30 MW installation linked to a combined heat and power (CHP) system in the region of North-Holland. The expectations are high and it is predicted that the plant will be constructed at the beginning of 1998, run for a few years on trial and subsequently be sold to a user, for example UNA (E&MSpectrum 1993b).

During the project, several established actors in the Dutch energy system express their serious interest in this technology, which results in an advocacy coalition formation (F7). This, in turn, leads to a mobilisation of resources (F6) (1.5 million EUR for the complete project) and more research to reduce the initial technical and economic uncertainties (F2). The entire initiative can be regarded as the creation of a niche market for gasification technology (F5), since the national government – backed up by the consortium of private parties involved – indirectly stimulates the potential returns by encouraging provinces to incorporate renewable energy into their energy mix (Daey Ouwens 2005a). The first phase of the North-Holland project therefore boosts several functions in the Biomass Gasification Innovation System.

Negotiations continue until 1997. However, one year before the construction is supposed to start, experiments demonstrate that the economics of the project are disappointing, in contrast with previously favourable outlooks, and that the North-Holland project is not economically profitable (E&MSpectrum 1997a; Faaij et al. 1998). In addition, there are uncertainties about the wood delivery. No suitable wood delivering company is found that provides long-term contracts (10 years), due to the uncertainty of wood prices (Daey Ouwens 2005a) (-F6). In addition, the pre-building time span stretches in such a way, that the liberalisation of the energy market starts to interfere with the project plans. This national liberalisation movement (which started in 1998 for the entire electricity sector) turns out to have dramatic consequences for this project, one of which is the growing fear that the SEP agency, one of the project partners, will be discontinued (DE 2001; Daey Ouwens 2005a). Furthermore, energy companies become reluctant to invest in high-risk projects. The fact that biomass gasification is an unproven technology results in insurmountable technological uncertainties. Therefore, the guidance of the search quickly shifts away from emerging energy technologies such as gasification (F4) (DE 2001; Daey Ouwens 2005a).

"The delays for realisation of biomass units is not only due to technical aspects, but due to the energy world that is reluctant to take high risks in the continuously proceeding liberalisation and due to the reduction of oil prices. Expensive and risky projects are not realised without problems by the free market anymore." (DE 1997d)

Finally, the Province of North-Holland and the energy company ENW (successor of PEN) decide to abort their ambitious gasification project in 1998 (Afval! 1998; Biovisie 1998b; DE 1998d). The final decision is caused by a build-up of disappointments in the technology and growing disagreement between the parties involved with respect to various technical and economical aspects, i.e. the unreliability of the technology, high costs and high risks (DE 2001).

7.2.3 The Tedious Trajectory of the Amer-Plant, 1996-ongoing

The second large-scale project is started in 1996, three years after the initiation of the North-Holland project, by a consortium of PNEM[12], NUON[13], EPZ[13] and BFI[14] (F1). The size of the plant is planned to be 30 MW with an atmospheric circulating fluidized bed (ACFB) gasifier for co-firing, where the combustible gas from the gasifier will be co-combusted in the nearby coal-fired power plant 'Amer-plant', operating with a CHP-unit, delivering 600 MWe of electrical power as well as up to 350 MWth of district heating (DE 1996a; E&MSpectrum 1996a; MilieuTechnologie 1996a; E&MSpectrum 1996b-b; EssentEnergieBV 2001). Once again, the expectations are high. It is promised that the plant will be operational in 1998, as shown by the following quote (F4) (DE 1996a):

"This plant will convert construction- and demolition wood into combustible gas, which can be co-combusted in the Amer-plant. There are several advantages of wood gasification: 46.000t coal will be saved, 115.000t CO_2 emission reductions will be achieved and 100.000t less wood waste will be dumped. From a feasibility study it is evident that such a plant will be profitable. If the construction starts by the end of 1996, then the plant will be operational in 1998."(DE 1996a)

However, shortly after, the consortium aborts the project because the use of waste wood proofs to be economically unfeasible for this application (F6). It turns out that it is more profitable to export the cleaned demolition wood to Sweden, than to use it for biomass gasification in the Amer-plant. This results in a lack of biomass resources to run the plant (DE 1996b). However, expectations of biomass gasification technology are still high and in 1997, EPZ restarts this project. This time, however, with a different wood delivery company (DE 1997c-a). The preparations pass off quickly and plans are that the plant will be operational in two and a half years:

"The plans for constructing a wood gasification plant on the site of the Amer-plant in Geertruidenberg by the electricity company EPZ is in an advanced stage. (…) The internal publication of EPZ writes that 'this is about a world premier'. The technology is new and has not been applied on commercial scale in combination with an electricity plant". (DE 1997c-a)

In 1998, subsidies are received from the European Union (F6) (Thermie programme, 5 Mio. EUR) and the Dutch government (CO_2-emission reduction plan, 6 Mio. EUR) and in 1999 the construction of the gasification plant enters the last phase; it should be finished by the end of the year (DE 1997c-a; DE 1998c-a; DE 1999b). In 2000, the construction is completed and the installation should be operational. The project receives much exposure in the (renewable) energy system of the Netherlands, as shown in the following quote:

> "There are high expectations for the Amer-plant, where the gasified biomass is blown into the nearby coal plant. This project is just starting and any positive experiences could mean the long awaited breakthrough". (DE 2000e)

However, positive experiences fail to occur. Technical problems hamper a smooth running of the gasifier, making modifications necessary. The major problems are the gas cooling (from 900° C to 220°C) and gas cleaning, since the contractor, Lurgi[15], has no experience with waste wood, but only with coal. The behavior of the waste wood ash is different, clogging up the exhaust and causing congestion (EssentEnergieBV 2001; Morris et al. 2005). In 2001, a temporary modification is carried out, marking a second phase of operation, in which numerous other – more structural – modifications are carried out. Both the gas cleaner and gas cooler are rebuilt to accommodate the properties of the ashes. Finally, in 2003, the plant is operational nearly full-time, as most of the problems – especially the gas cooling problem – have been solved due to the modifications (Willeboer 2005). From 2004 onwards, the contract with Lurgi is discontinued and Essent takes over the maintenance and operation of the gasification unit, since enough knowledge and experience (F2) have been built up over the years. Finally, on the 1st of September 2005, after seven wearisome years (during which only few kilowatt-hours have been produced), the modifications of the plant are finalised (Willeboer 2005).

The story of the Amer-plant shows that the high expectations of biomass gasification were just too optimistic and turned out contra-productive. Note that in 1992, the gas-cleaning problem was considered to be a technical problem, which could easily be resolved. However, it turned out to be one of the main problems, postponing a smooth functioning of the Amer-plant for seven years. Part of the reason for this problem is that the contractor did not have the necessary experience and expertise to foresee and resolve technical problems that would occur during biomass gasification. These problems might have been avoided if an experienced contractor would have been involved.

7.2.4 The breakdown of expectations, 1998-2002

Now that we have described two projects more in detail, we will return to describing the developments at system level.

In 1998, the energy market is liberalised and the waste market deregulated. Despite the high expectations in the previous period, biomass gasification failed to prove itself as a reliable, economically attractive, and efficient technology. The North-Holland project is aborted in this year and it is still unclear how the Amer-plant will turn out to perform. The choice of the main industrial parties in the liberalised market is not to use biomass gasification technology:

"Energy companies have not embraced biomass gasification yet; partly it is still in demonstration phase and not a proven technology yet […]. Furthermore, the liberalisation of the energy market makes energy companies reluctant to take risks. Companies prefer proven technologies rather than doing innovative things." (DE 2004a)

As a result, hardly any research and development on biomass gasification for electricity production occurs in the following two years (F2). The hype of gasification clearly ends here (F4) (DE 1998c-a).

In 2000, the government antagonizes all further developments related to biomass gasification, by formulating a strict emission regime based on current coal combustion plants. The few initiatives for small-scale biomass gasification plants[16] are immediately unprofitable under the new rules, since now additional gas cleaning is needed to comply with these rules (F4) (DE 2000a). As a consequence, no further research and exploration activities are carried out (F2), bringing the development of biomass gasification for electricity production to a halt. In this period, a vicious cycle becomes dominant, since there is no guidance of the search (F4), resulting in a lack of demand and expectations (F4), causing no more research to be funded (F5) and carried out (F2).

7.2.5 Revival of biomass gasification? 2002-2004

However, in the period 2002-2004, a revival of biomass gasification seems to occur. The drive for this revival comes from a different direction. The European Union stimulates its member states to substitute part of the fossil-based automotive fuels by bio-fuels. In the Netherlands, so-called 'second generation' (2G) biofuels – partly based on gasification technology – are preferred over the so-called 'first generation' (1G), which can be associated with conventional technologies (Stromen 2002; NRC 2004). This results in publicly financed research programmes – most notably the GAVE platform – to develop the conversion technologies necessary for the production of these fuels, e.g. most notably the NECST/NEO programme in 2001 and the GAVE subsidy programmes in 2001 and 2002 (F2, F4) (SenterNovem 2001; Stromen 2003b). From 2001 on, a large number of entrepreneurs and research institutes – Shell, ECN, etc. – conduct fruitful R&D on gasification processes for the production of Fischer-Tropsch Diesel and

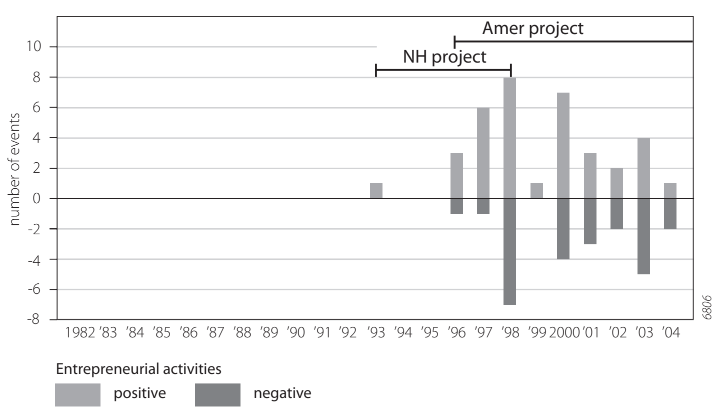

Figure 7.1 Activity pattern of System Function 1: Entrepreneurial Activities

hydrogen. As a consequence, this period is characterised by many renewed guidance activities on behalf of the national government (F4) and R&D activities by entrepreneurs and researchers (F2) (Boerrigter et al. 2002).

> "The chances for a large-scale application of biomass in the Netherlands are high. Also the use of biomass for bio-fuel production is expected to increase to 10% in Europe, this could be achieved from linseed or rapeseed or by gasification of biomass." (DE 2003f-a)

However, when the pressure of the EU to comply with the biofuels directive increases in 2003-2004, the 2G bio-fuels technology is still not ready for market introduction. As a result, the support for the 2G bio-fuel trajectory shifts to the background as the conventional fuels become more popular (Suurs and Hekkert 2005). Finally, history seems to repeat itself as technological optimism turns into disappointment within a very short period of time.

7.3 Functional Pattern

In this paragraph, the functional patterns are described by using graphical representations; the number of events per function per year is plotted over time. The patterns observed are explained by referring to specific events within the storyline, as given above.

All figures show a remarkable absence of activity before the 90's (see Figures 7.1 to 7.5). In the 90's things change; the main driving force within the Biomass Gasification Innovation System now is the search for alternative energy technologies to replace fossil fuels. As a result, several research programmes are set up to assess the application of gasification technology for energy production (F4, see Figure 7.4 peak in 1992). Experimentation and research provide positive results (F2, see increase in knowledge development activities from 1991-1998 in Figure 7.2). Expectations grow as biomass gasification is increasingly mentioned as the solution to a sustainable energy production (F4, see Figure 7.4 peak in 1995 and 1997-1998). This sequence of events corresponds with a positive interaction between the System Functions: the more research is done (F2, Figure 7.2), the more positive results are obtained and publicised (F3, Figure 7.3), the

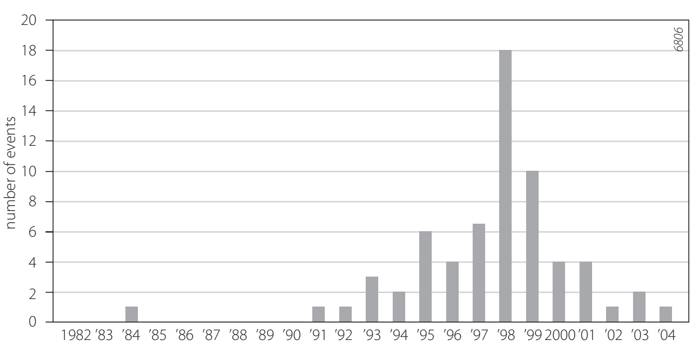

Figure 7.2 Activity pattern of System Function 2: Knowledge Development

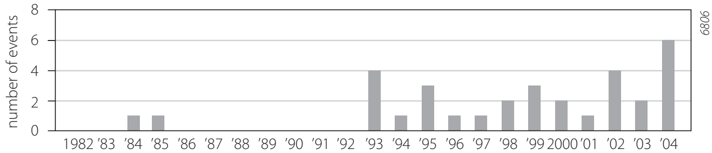

Figure 7.3 Activity pattern of System Function 3: Knowledge Diffusion

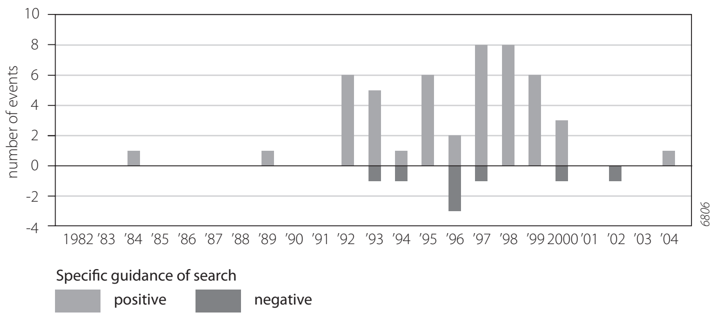

Figure 7.4 Activity pattern of System Function 4: Guidance of the Search

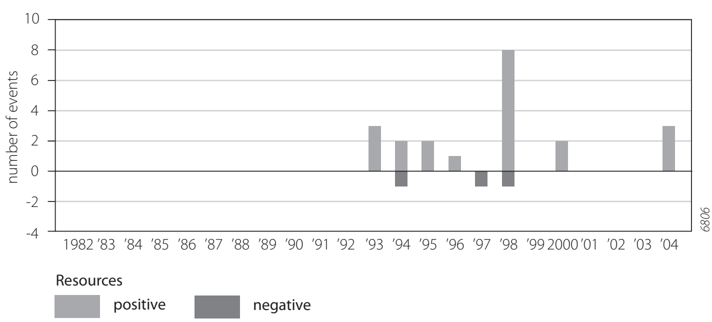

Figure 7.5 Activity pattern of System Function 6: Resource Mobilisation

more resources are allocated to the technology (F6, Figure 7.5), ensuring further development of biomass gasification (F2, Figure 7.2). This, in turn, stimulates entrepreneurs to take their chances and set up two large-scale plants for biomass gasification (F1, Figure 7.1). Throughout those years, other small-scale plants are set up as well (F1, Figure 7.1 peak in 1998). Thus, between 1992 and 1998, different System Functions are fulfilled, driven by high expectations, resulting in the build-up of a virtuous cycle.

However, in this period (1992-1998), actors of the Biomass Gasification Innovation System express their disappointment and reveal system flaws (see Figure 7.6 and the quotes in the gasification story line). This shows a lack of activities, resulting in some System Functions to be hardly or negatively fulfilled. For example, actors express their disappointment; their main

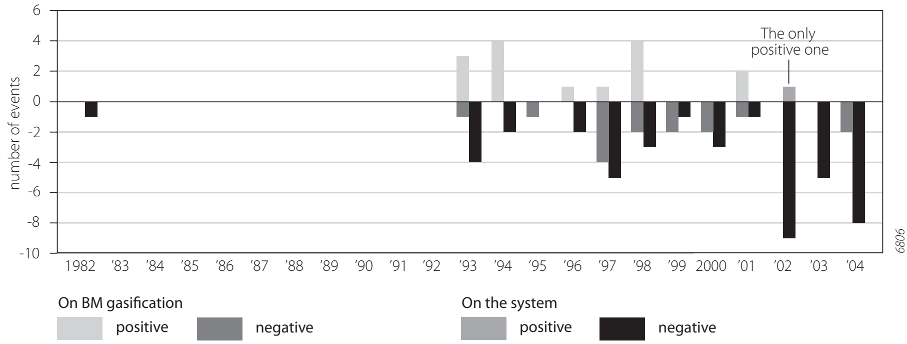

Figure 7.6 Activity patterns of actors' opinions within the Biomass Gasification Innovation System

concern is the fact that the national government does not provide uniform, consistent, and long-term regulations throughout the years (see Figure 7.6, negative opinions about the system). In this figure, the actors' opinions are counted over the years; the representation shows that there are more negative opinions about the system than positive ones (only one in 2002). Thus, we see that the technology itself is perceived as positive, but the Innovation System is criticised heavily. In addition, some actors are sceptical about the hype around biomass gasification technology; they warn entrepreneurs not to be carried away without proving the technology first (see Figure 7.6, negative opinions about biomass (BM) gasification). In retrospect, these voices seem to have made an accurate analysis. Furthermore, there are expressions about the lack of resources (see Figure 7.5 negative line) and the lack of support from advocacy coalitions (F7, no graphical representation due to few data). Nonetheless, in the period of 1992-1998, it seems that these negative or lacking System Functions are outweighed by the positive build-up of activities, due to the hype and high expectations that dominate that period.

However, as the energy market is liberalised in 1998, the high expectations are shattered quickly. Unsolved technical problems and a poor economic performance ensure that biomass gasification is not ready for introduction in a turbulent market environment. This results in the discontinuation of the North-Holland project (Figure 7.1, see markings in the graph) and the closure of several other small-scale plants that had been set up in previous years (Figure 7.1, see negative peak of projects aborted in 1998). In addition, most of the other activities in the Innovation System are discontinued as well; entrepreneurs and energy companies are reluctant to take high risks within the context of a liberalised market. No more research and studies are carried out (Figure 7.2, drop of positive line after 1998), allocation of resources (F6, see Figure 7.5, drastic drop of positive line in 1998) and specific guidance (F4, Figure 7.4, drop after 1998) for biomass gasification are discontinued. In addition stricter emission regulations are introduced in 2000, which results in the shut down of several small-scale plants (see Figure 7.1, negative line between 1999 and 2004 representing the shut-down of small-scale plants). Thus, the sequence of events after 1998 results in the collapse of the previous virtuous cycle.

The revival around biofuels seems to bring biomass gasification technology back on the political agenda as a key technology for 2G fuels, however no increase of other activities occurs then. The critics on the Innovation System remain highly negative, due to inconsistent government policy that did not manage to realise a breakthrough for the 2G biofuels (see Figure 7.6 negative opinions about system).

7.4 Conclusions

Despite the promises of high-energy conversion efficiency and the wide variety of applications, biomass gasification has not been successfully developed and implemented in the Netherlands. We applied the Functions of Innovation Systems framework to obtain more insight in the dynamics of the Biomass Gasification Innovation System and the determining factors that induced or blocked the evolution of this new technology. The most important insights gained are highlighted below.

The main inducement factors for the evolution of biomass gasification – in the period studied – are the high expectations and optimism about biomass gasification being an efficient and profitable energy production technology. This results in the initial hype where the build-up of the Biomass Gasification Innovation System becomes a reality; System Functions such as entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search and resource allocation mutually reinforce each other in this period. This virtuous cycle lasts for a period of six years (1992-1998).

One of the important blocking mechanisms arises when two drastic changes occur in the institutional system within which biomass gasification technology develops. Firstly, when the energy market is liberalised in 1998 and, secondly, the emission regulations are changed, biomass gasification technology has not booked enough positive results to be accepted as a proven technology. Many actors become reluctant to further support biomass gasification, which results in the abortion of various initiatives and activities. This is reflected in the decline of function fulfillment, i.e. no more entrepreneurial activities, decreasing knowledge development, no more specific positive guidance, and no more resources allocated to biomass gasification.

The main blocking factor – throughout the entire period – is the absence of the national government with respect to a clear and consistent policy towards biomass gasification. Over the years, the opinions of actors within the biomass gasification innovation system show that there is an absence of available public resources, guidance, and other forms of support for biomass gasification.

From our case it seems reasonable to assume that gasification technology still needed a protective environment to be able to further develop. Instead, the above-mentioned events forced the entrepreneurs to move to a free market environment and to either accept or completely reject the technology. When a new technology is served-off like this, two opposite conclusions can de drawn. The first is that the Innovation System was successful in screening out unfit technologies and the second is that the Innovation System did not function well enough to protect emerging technologies in the market environment. In this case, clearly the second conclusion needs to be drawn since for a technology to be declared incompatible, many experiments should be carried out first that show that the technical problems cannot be solved. In the Netherlands, though only one project was realised and after several years the technical problems were solved. For an emerging technology to have any impact, it normally has to go through a lengthy, uncertain and painful process of trial and error. However, in this case, only one project went through this process, all other projects were already dismissed before the first trial phase. Thus, the general conclusion that can be drawn from this, is that a structural misalignment occurred between the institutional framework within which the technology could have been developed, on the one hand, and the technical requirements on the other. Here, the government should have intervened by creating the right conditions for emerging technologies like biomass gasification, for instance by stimulating several System Functions, for example a niche market formation.

Notes

1 Originally published as Simona O. Negro, Roald A. A. Suurs, Marko P. Hekkert. (2006) "The Bumpy road of Biomass Gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system" in *Technological Forecasting and Social Change*

2 Dr. Andre Faaij, Associate Professor, Department of Science, Technology & Society, Utrecht University (2005); Professor Cees Daey Ouwens, initiator of the North-Holland project (2005); Dr Wim Willeboer, Senior project manager of the biomass gasification project of the Amer-plant (2005)). Additional interviews are included that have been carried out in a previous study (Florentinus 2004): Ir. Kees Kwant, program leader for EZ and VROM at Novem (2003); Ir. H.E.M Stassen, founder of BTG (2003); Dr. Andre Faaij, (2004); Professor Cees Daey Ouwens, (2003); Dr Wim Willeboer, (2004).

3 Novem is an agency of the Dutch Ministry of Economic Affairs focusing on energy and environment.

4 Provincial Council of the province of Noord-Holland (North-Holland)

5 Since 1986 there are nine small-to-medium scale (5-10 MWth) 'Bioneer' fixed bed gasifiers operating in Sweden and Finland [16, 38].

6 In the late 1990s, pressurised gasification technology is successfully demonstrated in the world's first complete BIG-CC power plant in Värnamo, Sweden. The plant aims at demonstrating the complete integration of a gasification plant and a combined-cycle plant, fuelled by biomass; the basic idea is to demonstrate the technology rather than to run a fully optimised plant. Between 1996 and 2000 a demonstration program is run to verify status and future potential of BIG-CC from a technical and economical point of view, but after the demonstration program is concluded, the plant is mothballed in 2000 since it is not economical to operate the plant given the low electricity prices in Sweden [16, 38]

7 In 1998 the commercial demonstration of the Lathi gasifier (60 MWth) is realised and is still operational today. In 2002 a similar plant (50 MWth) to that at Lahti is taken into operation in Ruien, Belgium [16, 38].

8 Thermie – Non-Nuclear Energy Program, 1990-1994

9 In Dutch: Nationaal Onderzoek Biomassa programma, NOB

10 From 1948 until 1998, the 'SEP' was the coordinator of the national energy companies

11 ECN is the Energy research Centre of the Netherlands; From 1994 on ECN carries out several feasibility studies, among others for the North-Holland project, on various biomass streams (organic waste, wood, paper etc) and on the economical and technical potential of integration of a gasifier and a gas turbine. In 1996 a circulating fluidized bed, BIVKIN, is set up, with the aim to collect information about the gasification process and properties of different biomass streams. In a short period of time the gasifier becomes a reliable

installation due to the collaboration of ECN, Stork, HoSt, Afvalzorg and Novem. In 1999 the gasifier is equipped with a gas cleaner developed by HoSt and plans are made to apply the technology commercially (E&MSpectrum 1995a).

12 Dutch energy companies

13 NUON and EPZ are energy production companies

14 Waste processing company now called SITA

15 Lurgi: German technology company operating worldwide in the fields of process engineering and plant contracting. The Lurgi process is one of the original developers of conventional gasification processes (www.lurgi.de)

16 Between 1993 and 2000 several small-to-medium-scale (100kW to 8MW) gasification projects are planned and some are set up by BTG, TNO, ECN, Goor, HoSt, Edon, Stork, Kara etc. [73]

8 Stand-alone biomass combustion compared to co-firing and biomass gasification in the Netherlands[1]

8.1 Introduction

In this chapter, three technology trajectories will be compared, i.e. stand-alone biomass, combustion co-firing, and biomass gasification. The reason to compare these technologies is that, ever since the 90s, they have been competing for the same resources and institutional support. Although the technologies started off with the same aim to produce electricity from biomass, the development of the three technology trajectories turned out to be quite different. Therefore, it is interesting to understand the underlying factors leading to a different development, diffusion, and implementation of these three technologies. Aim of this chapter is not to judge, which technology is best, but to identify the carriers or barriers that support or hinder the development and diffusion of a technology, as to provide insight into how to accelerate the diffusion of emerging renewable energies.

Thus, the research question for this chapter is:
How can we explain the differences in evolution between biomass co-firing, combustion, and gasification?

8.1.1 Notes on Methodology and Technical Aspects

The same theory and methodology as described in chapters 2 and 3 are applied to this case study. In the historical analysis, the key processes taking place within the biomass energy Innovation System are highlighted. The symbols F1 – F7 refer to the seven System Functions that are the focus of this thesis, as described in Chapter 2.4.

The description and analysis of biomass gasification will be based on chapter 7. For biomass combustion, the same methodology is used as described in chapter 3 (i.e. literature search, historical event analysis). The trajectory of biomass co-firing has already been analysed and the storyline will be based on that study (see (Raven 2005)). Additional information on co-firing has been collected via websites, reports, and grey literature. Thus, my analysis will be based on the study by Raven and on additional empirical material.

The time period of analysis for all three technologies runs from 1990 until 2004. However, more recent events, such as the construction of plants and severe changes in institutional conditions, have been included on an incidental basis.

8.2 Historical Overview of Biomass Co-firing, Biomass Gasification, and Biomass Combustion, 1980-2004

8.2.1 Introduction

Since the oil crises in the 70s, the awareness of the finite amount of fossil fuels has increased and the Dutch Government publishes two 'Energy White Papers' (1974 and 1979) as to stimulate energy saving (F4) (TweedeKamer 1974; TweedeKamer 1979). However, as the oil prices drop in the 80s, the energy saving issue disappears temporarily from the political agenda (-F4). In the late 80s, the environmental awareness is raised once again after the publication of an influential report[2], which stimulates the government to publish the first 'National Environmental Plan[3]' (NMP) and, shortly after, the 'White Paper on Energy Saving[4]' (F4) (VROM 1989b; EZ 1990). In these plans, all participants of the Dutch economy are addressed with respect to their own responsibility to contribute to energy saving in the Netherlands. A major responsibility is put on energy firms to reduce the energy consumption of their customers (VROM 1989a). This inspires the energy firms to publish the first 'Environmental Action plan[5]' (MAP-I) in 1991, and to take the social responsibility to provide a substantial contribution to a sustainable and environment friendly energy supply (F4) (ECN 1994; EnergieNed 2000). In this plan, measures are elaborated to achieve a CO_2 emission reduction of 9 million tons by 2000, i.e. a 10% reduction (EnergieNed 2000). These goals towards a more sustainable development are taken over and sharpened by the government in the second 'National Environmental Plan' (NMP-Plus) and a second 'White Paper on Energy Saving[6]' (F4) (EZ 1993). As a result, after three years, the CO_2-reduction goals are doubled to 17 million tons in the third 'Environmental Action Plan' (MAP-III) (EnergieNed 2000). Reasons for the alteration are the continuous economic growth and the respective increase in energy consumption; research commissioned by the energy sector demonstrates the feasibility of the energy firms to reduce the amount of carbon dioxide[7] (F2) (EnergieNed 2000).

Thus, in this period, strong guidance of the government is the key driver leading to actions to reduce CO_2 emissions.

Besides the need to reduce CO_2 emissions and to produce renewable energy, the Netherlands struggle with the problem of waste and agricultural surplus. Research leads to the recognition that combustion technology is a promising option to reduce waste and agricultural surplus, with the additional benefit of producing energy (F2) (NE&S 1981c; NE&S 1982e; NE&S 1983a; Davids 1984; Novem 1984). To prevent emission increase, the Ministry of Environment[8] introduces several emission regulations (BEES A[9], Richtlijn Verbranden[10]) to limit the air pollution, expected to increase upon augmented waste combustion (F4) (VROM 1987; EnergieConsulent 1989). In addition, several research programmes are set up on a national level – such as the EWAB[11], NOH[12], and 'Ten Years Waste Programme'[13] – and on a European level – such as the Thermie[14] and Joule[15] Programme -, to increase knowledge and to guide the energy production from waste and biomass (F2, F4) (DE 1989b; DE 1990; EU 1990; TweedeKamer 1990; E&MSpectrum 1992). The knowledge obtained within the research programmes leads to further research into reducing emissions, improving the efficiency of energy production, and finding appropriate biomass streams and efficient conversion technologies (F2) (DE 1991a; DE 1991b; EnergieConsulent 1992; DE 1992e-b).

However, the results obtained do not correspond with each other and represent the divisions within the energy sector and the competition between the available technologies.

On the one hand, waste wood, demolition wood, and thinnings play an important role in the EWAB programme for small-scale stand-alone biomass combustion plants (F4) (DE 1992f; DE 1992i). On the other hand, the director of the United Electricity Producers, SEP[16], Mr Ketting, consideres the use of large-scale electricity plants a solution to the waste problem. By co-firing waste wood, a certain percentage of coal is replaced which reduces emissions; the wood waste is usefully processed (F4) (EnergieConsulent 1992; DE 1992j). However, from the research side, the preference lies with biomass gasification, due to its higher energy conversion efficiency and flexible output (such as electricity or syngas that can be used for various applications) (DE 1992d; DE 1992e-b). These different results lead to the development of several technological trajectories in the following years, where research and resources are distributed among co-firing, combustion, and gasification.

Below, an overview of the trajectories of co-firing, biomass gasification, and biomass combustion is given to illustrate the development and diffusion of these technologies.

8.2.2 Co-firing of Biomass in Coal Plants

The first co-firing experiments start in the early 90s (F1). Driver is the agreement between the energy firms and the government in the MAP to reduce 17 million tons of CO_2 emission by 2000 (F4) (DE 1990; TweedeKamer 1990; E&MSpectrum 1992; EnergieConsulent 1992). The experiments turn out to be successful and promising (F2) and show that technical problems are solvable (F4). As a result, the Dutch energy firms apply for permanent permits for co-firing in the mid 90s (F1) (DE 1995g). By 2000, most of the Dutch coal plants co-fire permanently up to 5% of biomass in their plants (F5) (DE 1996q; DE 1997g; Raven 2005). Financial resources are provided by budgets reserved within the MAP agreement and biomass availability is ensured by local and national collection or import (F6). However, long permit procedures delay several projects in the course of years, and both neighboring residents and environmental organisations protest against the co-firing of biomass (-F7) (Stromen 2001d; Stromen 2001f; Stromen 2001i). Additionally, contradictory emission rules and the lack of categorisation of biomass and waste also result in the projects' delay and high costs (-F4) (DE 1998u; Stromen 2001c).

The two existing ministerial orders (BLA and BEES-A)[cb] dictate the emission standards for waste incinerators and for energy plants respectively, where a third standard (NER) prescribes emission standards for any other case (Stromen 2001c; Raven 2005). However, confusion remains in those cases in which waste – which is subject to the BLA standard – is combusted in plants subject to the BEES-A standard (Stromen 2001c).

Finally, after several years of lobbying by the Dutch energy firms (F7), the Ministry of Environment presents an emission framework (F4), based on a distinction between clean ('the white list') and polluted ('the yellow list') organic material, to be applied independently of the type of plant (see Table 8.1 for an overview of emission standards) (Stromen 2000f; Stromen 2000g; Stromen 2001c). This emission framework is attached to the 2002 'Coal Covenant' (F5) (ECN 2002). The coal covenant is introduced, as the emissions of CO_2 need to be further decreased (Stromen 2000g). A new target is set to reduce 5.8 million tons of CO_2 between 2008 and 2012; to realise this target, the production firms can either switch from coal to natural gas, close down a coal plant, or co-fire biomass (i.e. the coal share has to be replaced with app. 20% of biomass in the short term and with app. 40% in the mid term, resulting in a co-firing capacity of 475 MWe (ECN 2002; IPO 2003). In exchange for the latter option, the government will not

Table 8.1 Overview of emission standards

Year	Emission rules	Content
1992	BEES-A: Order for Emission Standards for Boilers[1]	Order that dictates emission standards for energy generation; limits for NO_x, SO_2 and dust.
1993	BLA: Order for Emissions to Air from Waste Combustion[2]	Order that dictates emission standards for waste combustion; limits for mercury, heavy metals, and dioxins.
1998	NER-standard[3]	Order that dictates emission standards for any other case.
2002	Coal Covenant	Framework based on a distinction between clean organic material ('white list') and polluted organic material ('yellow list'). The combustion of materials on the yellow list is subject to emission limits for NOx, SO_2, and dust. Combustion of materials on the yellow list is also subject to limits for other toxins.

1 In Dutch: Besluit emissie-eisen stookinstallaties milieubeheer A
2 In Dutch: Besluit luchtemissies afvalverbranding
3 In Dutch: Nederlandse Emissie Richtlijn

imply new regulations for the emission of polluting substances (Hg, NO_x and SO_2), as the levels are already lower than dictated by European regulations (ECN 2002).

The introduction of the coal covenant shows that the guidance of the government has two effects. On the one hand, this guidance exerts heavy pressure on the coal plants to reduce CO_2 emissions. However, on the other hand, it provides favourable conditions for biomass co-firing, as it forces energy firms to come up with alternatives that fulfill the covenant's goals (F4). Thus, in a short period of time, a niche market is created for biomass co-firing, as most of the coal plants implement this option (F5) (see Table 8.2 for an overview of the co-firing activities) (ECN 2002; Faaij and Juenginger 2005; Raven 2005).

To summarise, the fast development of co-firing from a small niche into one of the largest renewable energy niches in a short period of time (i.e. 10 years), results from the favourable technical aspects (reliable, cheap, low risk) and the market formation for biomass co-firing (F5). Trigger is the government's urgency to reduce CO_2, which leads energy firms to agree voluntarily (MAP) to contribute to the CO_2 emission reduction by developing several options, among which co-firing (F1). Since most of the technical problems are solved, co-firing is introduced permanently in coal plants in a short period of time. In addition, the costs are low (F5), as the plants have already been constructed and the infrastructure is available. In this case, the Technological Innovation System does not need to be built up from scratch, since most of the elements required for a Technological Innovation System – such as actors, institutions, networks, and organisations – are already in place. This is a typical example of hybridisation, as described by Geels[18] (2002).

The remaining barriers are contradictory permit regulations (-F4), which are resolved after several years of lobbying by the energy firms (F7), as the government introduces a clear categorization of biomass and waste streams. Furthermore, the lobby activities result in the alteration of the institutional conditions in such a way, that a market for biomass co-firing is formed in a short time period (i.e. exemption of coal plants from stricter emission rules if biomass co-firing is applied).

Table 8.2 Overview of co-firing activities in the Netherlands based on (Faaij and Juenginger 2005; Raven 2005)

Year	Plant	Co-firing concept	Total capacity (MWe)	Electricity production (GWh)	Fuel (estimated amount co-fired in 2004 (kton and type)
1996	Gelderland-13 (EPON -> Electrabel)	Direct	600	19.6	4 Demolition wood + olive seeds
1998	Maasvlakte 1+2 (EZH -> E.ON)	Direct	2x518	320	230 Biomass pallets, animal waste (bone meal)
1998	Amer-8 (EPZ/PNEM -> Essent)	Indirect	645	343	320 Paper sludge, food industry waste
1999	Borssele-12 (Essent)	Direct	403	187.6	108 Various organic sources
2001	Buggenum-7 (Nuon)[1]	Direct	253	6.8	Various organic sources
2002	Claus power plant (Essent)[2]	Direct	2x640	261	78 Vegetable oil
2002	Harculo (Electrabel)	Unknown	350	47.4	12 Bio-oil, cereals
Total				**1131.2**	

1 Coal gasifier
2 Natural gas plant

Thus, the most important System Function enabling the development, diffusion, and implementation of co-firing, is the formation of a market (F5) triggered by favourable institutional conditions through government guidance (F4). Additional factors are the willingness of the energy firms to contribute to the CO_2 emission reduction, favourable technical aspects of the technology, and the advantage of the presence of an infrastructure.

8.2.3 Biomass Gasification[19]

In Chapter 6, the evolution of biomass gasification was described, which differs considerably from the evolution of co-firing.

Main driving force within the Biomass Gasification Innovation System is the search for alternative energy technologies to replace fossil fuels. As a result, several research programmes (F2) are set up to assess the application of gasification technology for energy production, where experimentation and research provide positive results. Expectations grow as biomass gasification is increasingly mentioned as the solution to a sustainable energy production (F4). This sequence of events corresponds with a positive interaction between the System Functions: the more research is being performed (F2), the more positive results are obtained and publicised (F3), the more resources are allocated to the technology (F6), ensuring further development of biomass gasification (F2). This, in turn, stimulates entrepreneurs to take their chances and set up two large-scale plants for biomass gasification (F1) (see Table 8.3).

Table 8.3 Overview of biomass gasification plants

Year	Plant	Gasification concept	Total capacity (MWe)	Electricity production (GWh)	Fuel (estimated amount co-fired in 2004 (kton))	Status of plants
1993 1998	Northern Holland UNA	BIGCC with CFB	20-30 MW	/	/	Terminated in planning stage.
1995-1996; 1997-2000	Amer plant, Geertruidenberg Essent	Co-firing with gasification	~30 MW, 83 MWth[1]	n.a.	150 ktons of construction and demolition wood	In operation.

1 (Loo and Koppejan 2002)

Thus, between 1992 and 1998, the System Functions mentioned above interact with each other and the build-up of a virtuous cycle ignites, strongly dominated by science and high technological expectations.

In the same period, other actors of the Biomass Gasification Innovation System express their disappointment, as the national government does not provide uniform, consistent, and long-term regulations throughout the years (-F4). In this case, the technology itself is perceived as positive, but the Innovation System is criticised heavily. In addition, some actors are skeptical about the hype around biomass gasification technology; they warn entrepreneurs not to get carried away without proving the technology first. Furthermore, a lack of resources (-F6) as well as a lack of support from advocacy coalitions (-F7) are expressed.

However, these negative or lacking System Functions seem to be outweighed by the positive build-up of activities, due to the hype and high expectations dominating this period.

Yet, as the energy market is liberalised in 1998, the high expectations are shattered quickly (-F4). Unsolved technical problems and a poor economic performance prevent the introduction of biomass gasification in a turbulent market environment. This results in the discontinuation of the North-Holland project and of several small-scale plants that had been set up in previous years (-F1). In addition, most of the other activities in the Innovation System are discontinued as well; entrepreneurs and energy firms are reluctant to take high risks within the context of a liberalised market (-F1). No more research and studies are carried out (-F2) and the allocation of resources (-F6) and specific guidance for biomass gasification are discontinued (-F4). In addition, stricter emission regulations are introduced in 2000, which results in the shutdown of several small-scale plants. Thus, the sequence of events after 1998 results in the collapse of the previous virtuous cycle, due to technical problems and a lack of guidance (F4) and market formation (F5).

The revival around biofuels seems to bring biomass gasification technology back on the political agenda as a key technology for second generation fuels[20] (F4). However, this causes no increase in other activities. The criticism on the Innovation System remains highly negative, due to inconsistent government policy unable to realise a breakthrough for the 2G biofuels (-F4).

Main blocking mechanism is the lack of government guidance to provide clear and consistent policies (-F4) plus the lack of a market niche (-F5), where the actors could have experimented and built up experience with the technology. At the beginning, the expectations of biomass gasification to be the solution are high, but due to unsolved technical problems and inconsistent government guidance (-F4), the opinions change drastically as the energy market is liberalised. The liberalisation comes too early for gasification, as it is still an unreliable and expensive technology. Besides the unfortunate timing of the liberalisation, no additional time and space are allowed for trial and error, as to solve the technical problems. Investors and government consider the technology unfit and unworthy for further support (-F7), which results in the collapse of the Biomass Gasification Innovation System.

8.2.4 Stand-alone Biomass Combustion

1990-1999: Setting the Scene

In the early 90s, the energy firms have voluntarily agreed with the government to reduce CO_2 emissions and to save energy. Several technological options are explored; the easiest turns out to be biomass co-firing in coal plants. The replacement of coal by biomass reduces CO_2 emissions and the energy share produced by biomass is considered renewable energy. However, increasing international pressure[21] plus economic and environmental reasons trigger the Dutch Ministry of Economic Affairs to publish the 'Third White Paper on Energy'[22], describing the latest plans to move towards a renewable energy supply (EZ 1995). Aim is to achieve a 10% share of renewable energies by 2020, of which biomass should contribute 44% (EZ 1995).

One way to increase the share is the introduction of the 'Regulating Energy Tax[23]' in 1996. This is an energy levy on conventional electricity and gas consumption by small- and medium-size customers. However, electricity produced from biomass is exempted, and 1.5 eurocents/kWh are obtained. In addition, if CHP is combined with biomass, yet another 2 eurocents/kWh are obtained (F5) (EnergieNed 200?; E&MSpectrum 1996b-a; EnergieNed 2000; Faaij and Juenginger 2005). In the period of 2000-2004, all renewable energy is exempted from taxes, where premium tariffs for renewable energy producers of 8 eurocents/kWh (6 eurocents/kWh tax exemption + 2 eurocents/kWh) are obtained (F5). The introduction of this tax is a positive instrument to create a market for biomass energy. However, it has averse effects when large amounts of electricity are imported by energy firms instead of increasing the construction capacity in the Netherlands. Therefore, the REB is phased out in 2003 and replaced by the MEP feed-in tariff system, paid to electricity producers from renewable energy sources who feed in on the Dutch electricity grid (F5) (Faaij and Juenginger 2005).

Then, in 1997, the Dutch Government implements the 'CO_2 reduction plan'[24] as a consequence of signing the Kyoto Protocol[25] (SenterNovem 2005). Projects that fall within the climate change policy of the government can apply for subsidies. This results in the setup of several projects, as subsidies are now available.

Another way is the liberalisation of the electricity market, which occurs in several steps from 1998 onward (F4). In 2001, the liberalisation of the renewable electricity market occurs, which enables energy distribution firms to compete for households on the renewable market three years earlier than on the fossil market (F5) (Faaij and Juenginger 2005).

Table 8.4 Overview of stand-alone biomass combustion plants in the Netherlands in 2004 (Kuiper 1999; Novem 2003; Junginger and Faaij 2005)

Year	Plant	Combustion concept	Biomass capacity (MWe/year)	Electricity production (GWh)	Fuel (estimated amount co-fired in 2004 (kton))
1995	De Lier De Lange	CHP-installation of 3 MW	0.75 (in 1999)	n.a.	6 (in 2002) Sawdust, wood fibre
1996	Schijndel HIS	Grate firing with a steam cycle	1.2 (in 1997)	n.a	7 (in 2002) Clean wood
1996	Lelystad Nuon	Grate burner and steam turbine	1.3 (in 2001)	47	4 (in 2002) Forestry thinnings and residues
1997	Cuijk Essent	Bubbling fluidized bed boiler	25 (in 1999)	150	240 (in 2004) Clean wood chips
Total				**197**	

This new focus to increase the renewable energy supply (F4) leads to research (F2) on new technological options and to new initiatives by the energy sector and by other sectors in which the emerging renewable energy market is considered an opportunity (F1). The wood sector is interested as well, ever since the introduction of a ban on dumping combustible material, as to ensure that waste wood is cleaned and reused or processed to produce energy (F4) (E&MSpectrum 1996b-a). This stimulates firms with a wood surplus to opt for energy conversion, which is more profitable than having to pay for the processing[26] (E&MSpectrum 1996b-a).

First, several studies (F2) are carried out comparing several biomass technology options. Biomass combustion is preferred over biomass gasification, as it is a proven technology, commercially available, and the energy efficiency is expected to be improved, from 14-18% to 30%, if technical improvements are carried out (MilieuTechnologie 1994a; E&MSpectrum 1994a; DE 1994g). The expectations of biomass technologies increase (F4) and several initiatives to construct stand-alone biomass combustion plants are observed in the period between 1995 and 1997 (F1). These initiatives can be divided into those by the energy sector and those by the wood-processing sector.

This sequence of events shows that favourable conditions are created for the development and diffusion of biomass combustion: as positive results are obtained (F2), the technology is acknowledged as a renewable energy option (F7), for which tax exemption (F5) can be obtained, resulting in the prompt formation of a market (F5). This encourages entrepreneurs to set up stand-alone biomass combustion plants, resulting in the production of green electricity by stand-alone biomass combustion plants between 1997 and 2001 (see Table 8.4) (F1).

Below, a more thorough description of the individual projects is presented. First, the two wood sector projects are described, after which the two projects initiated by the energy firms are clarified.

1995-1999: On the Brink of Breakthrough

'De Lange – De Lier', 1995 – Ongoing
The first stand-alone biomass combustion project is set up in 1995 (F1). The wood trading firm 'De Lange BV' takes over a wood combustion plant from a horticulturist who experimented (without success) back in 1984 with biomass combustion to heat his greenhouses (F2). 'De Lange' considers it an opportunity to process its own waste wood at low price, due to the ban on dumping combustible waste (F5). The firm decides to rebuild the old installation (F1). A consultancy agency and an engineering firm are recruited to carry out a feasibility study. A combined heat and power (CHP) installation of 3 MWth (240 GJ heat per day) turns out to be the best option (F2). Subsidies are obtained from the Thermie programme (F6) (E&MSpectrum 1997c; Biovisie 1998a). Throughout the preparation stage, information events for the local community and industry are organised (F3), resulting in no opposition (F7). However, as this project is the first of its type, several technical problems[27] delay the electricity production. This shows that, if experience is lacking, it takes time to come to results, even when a technology is perceived as a simple technology. In this case, a trial and error period is allowed to solve the technical problems. In April 1999, electricity is first produced, after having solved the technical problems (F1) (Novem 2003).

Drivers of this project are a combination of entrepreneurial spirit of the firm (F1), recognising the opportunity to process its waste surplus, and the regulation providing a profitable way to achieve this (F4). As a result, knowledge of the most feasible option is gained and technical problems are solved (F2). As to reduce the risk of delay, potential opponents are involved (F3, F7). The only problems that occur are of technical nature, due to the lack of experience. However, after several years of trial and error (F2), the problems are solved. The plant has been operating successfully since 1999.

'Houtindustrie Schijndel BV', 1996 – Ongoing
For wood firm 'Schijndel B.V.', the reasons to construct a bio-energy plant are the same as those of De Lange. Due to the ban on dumping combustible wood (F5), Schijndel starts, supported by Novem (F4), to look for a solution to efficiently convert its wood surplus (F5) (E&MSpectrum 1996b-a). The choice is made for a small-scale combined heat and power combustion plant; the electricity surplus will be delivered to the energy firm PNEM, thus providing app. 2000 households with green electricity (F5). Novem will finance one fifth[28] of the investment costs (as it is a CHP-plant) and the production of green electricity will be exempted from tax (F6, F5) (E&MSpectrum 1996b-a; Novem 2003).,The plant has been operational and producing electricity and heat since January 1997 (DE 1996g; DE 1996k; DE 1996v).

Driver of this project is the opportunity to convert wood surplus into renewable energy where tax exemption and subsidies are obtained (F5, F6). In addition, by delivering the electricity to PNEM that sells it to its customers as green electricity, market formation is guaranteed (F5).

The next paragraph depicts the plant setup by energy firms. As the energy firms agreed in the MAP to reduce CO_2 emissions and to produce renewable energy, and as the Third White Paper on Energy dictates a target of 10% of renewable energy by 2010 (nearly half of which should be provided by biomass), stand-alone biomass combustion is recognised as a potential option. These regulations instigate energy firms such as Essent and Nuon, to experiment and gain experience with stand-alone biomass combustion.

'Nuon – Lelystad', 1996 – Ongoing
In 1996, Nuon starts to gain experience with electricity and heat production from biomass (F2). The choice is made for a small-scale bio-energy plant providing electricity to the public electricity network and delivering heat to the local city heating system in Lelystad (DE 1997). This choice seems to promise success, as it is designed to accomodate the local amount of available biomass (DE 1998r). Local energy plantations will provide 10% of the biomass, the local forestry will provide the rest (F6). The capacity will be 15 ktons of oven-dried biomass on a yearly basis (DE 1997e; Novem 2003).

Nuon expects a subsidy of two million Euros from the CO_2 reduction plan, yet receives half a million Euros less than expected (-F6) (DE 1997k). As a result, the plans hang by a thread and Nuon has to decide whether or not it wants to pay the difference from its own MAP budget (E&MSpectrum 1997b; DE 1997k). Nuon decides to continue and looks for another subsidy source. The missing half million Euros are obtained from the NEWS regulation, as it concerns an energy saving heat and power system (E&MSpectrum 1997a). At last, the construction of the plant starts, expected to be operational by 1999 (DE 1998r). However, delays occur, as the international consortium does not have the required financial capacity and cannot fulfil the promises made (-F6). Nuon has to take over the construction and, as a result, the budget is exceeded and the electricity production delayed – as late as 2001 – whereas the project started back in 1996. Throughout the entire period, no opposition arose, due to the including and informing of nearby inhabitants (F7) (Novem 2003).

Driving force of this project is the entrepreneurial spirit of Nuon to gain experience in this field and to realise the goals as set in the MAP and the Third White Paper on Energy. This leads to secured resources, i.e. biomass (F6), and acceptance and support of surrounding communities (F7). The main problem lies in the innovation trajectory rather than in the technology. Due to a lack of financial resources (-F6), the project is delayed and costs are increased.

'Essent – Cuijk', 1997 – Ongoing
In the meantime, energy firm Essent is also interested in building a biomass energy plant. Most feasible option appears to be a large-scale combustion plant for electricity production. The reason to opt for this plant is to keep the risks to a minimum and to use a proven technology (DE 1997a; E&MSpectrum 1997b; DE 1997c-b). Aim of the project is to produce electricity in a renewable way, by using biomass combustion and to gain more experience with this conversion technology (Novem 2003). As Mr Remmers, project leader of Essent, explains:

> "Pre-studies showed that gasification technology in and of itself seemed feasible. However, the combination with a gas turbine for the production of electricity was too uncertain. Aim of Essent is to have the plant operational by 2000. This will indeed be necessary, if the goals of renewable energy production are to be achieved, i.e. 2.8% of the total energy production [29]." (DE 1998c-b)

For the financial part, subsidies are expected from the CO_2-reduction fund (F6). In case these subsidies are not received, the project may not be doomed straight away, yet the board of Essent will have to consider whether to continue the project or not (DE 1998c-b). Essent contracts a firm specialized in the logistics of waste streams, to collect national streams and to import foreign biomass, as the Dutch biomass market is too small to provide the input required for the large plant (EnergieVerslag 1999c; DE 1999i; Stromen 2001b; DE 2002i). Siemens delivers turnkey technology (F2), meaning it caries all responsibility. All of the electricity produced is sold as green electricity to Essent's clients (F5). At the beginning, several technical problems (i.e. 'bed agglomeration', congestion, etc.) arise and more wood is needed to reach the capacity of 25 MWe (Novem 2003). However, the technical problems are quickly solved and the plant is operational in 1999. Yet, the search for biomass continues throughout the years (-F6).

In 2003, the project is threatened by the delay of the introduction of a new feed-in tariff system (MEP), making the import of green energy more profitable. Nonetheless, Essent decides to keep the contracts with the biomass providers and continues to combust biomass in the town of Cuijk (DE 2003d). Once again, from an early stage onward, the local community is included and informed about the plans as to prevent opposition (F7).

Initial trigger of this project is the availability of subsidies from the CO_2 reduction plan (F6) and of obligations that energy firms agreed upon in the MAP. Additional factors are the low risk technology and the existence of a market to sell green electricity (F5). Market formation (F5) due to the liberalisation of the renewable energy market and the new feed-in tariffs ensure the continuation of the biomass plant of Essent.

To summarise, the underlying drivers for the projects can be described as positive interactions between the System Functions: the initial trigger is the guidance of the search (F4) by the government and the energy firms to achieve their goals of CO_2 emission reduction. This leads to further development of the technology (F2); positive results raise the expectations (F4) of entrepreneurs to engage with biomass combustion technology. Furthermore, institutional conditions are aligned (F4) in such a way, that sufficient resources are allocated (F6) to the technology, which leads to market formation (F5). As a result, entrepreneurial activities (F1) develop and biomass combustion plants are constructed. Thus, a positive build-up of System Functions develops (specifically guidance of the search and market formation) and, as a result, biomass combustion technology is further developed and diffused.

2000-2001: A Temporary Freeze

In 2000, despite the protest of the 'Platform Bio-energy' (F7), the Ministry of Environment introduces stricter emission rules for biomass energy plants (-F4). The new rules oblige biomass plants to add additional gas cleaning units, which results in high additional costs for future small-scale plants up to 7 MW (DE 2000c; Stromen 2000f). The Ministry hopes that, with stricter emission rules, the processing of rest wood will be promoted in large-scale biomass plants, as they produce lower NOx-emissions and have higher energy efficiency than small-scale plants (Stromen 2000f). In this case, the government shows a clear preference for large-scale plants, antagonising small-scale plants (F4). This indicates the attempt of the government to select a technological option in an early phase of development, instead of providing time for the options to develop first.

Mr G. Bergsma of CE[30] suggests that, instead of introducing stricter emission norms, more investments are needed to keep small-scale plants feasible as well:

Table 8.5 Overview of discontinued small-scale plants

Year	Plant	Biomass/Capacity	Status
1996-1998	Den Haag, Binckhorst	600 kWe grate firing, 10 kton waste wood	Discontinued after feasibility study by Eneco. CO_2 subsidy rejected, BLA emission targets not realisable, uncertainty about emission rules in general.
1998-2000	Hardenberg, ATO-DLO, Essent, Cogas	Energy crops with CHP	Discontinued after feasibility study by Essent. Energy crops too expensive, large uncertainty about fuel delivery. There is still interest for the CHP plant by Cogas and community Hardenberg.
2000-2002	Enschede, Eschmarke	1MWe, 4 MWth, Demolition wood, Combustion/gasification	Discontinued after feasibility study. Essent had no faith in gasification technology.
2000-2001	Heerveen	300 kWth (Talbott) Demolition wood, heat to horticulturist	Discontinued after feasibility study. Uncertainty about wood prices and difficulties contracting horticulturist. No remuneration for heat production.
2001-2002	Tilburg	2720t waste wood	Discontinued after feasibility study. High prices for waste wood, energy firms are not interested.
2001-2002	Berlikum	5 MWth Heat for glasshouses, 30000t Waste wood	Discontinued after feasibility study by 'Afvalsturing Friesland'. Difficulties contracting horticulturists; Essent does not participate, due to negative previous experiences with similar projects.
2002-2003	Almelo, Ekoblok	625 kWe CHP pyrolysis gases	Discontinued after feasibility study by Cogas. Financially unfeasible.

> "Already at this stage, plants like Lelystad (1.3 MWe) are not financially feasible (due to the NOx-emission rules). To stimulate biomass to become *the* renewable energy source, more subsidies for such plants will be necessary or rest wood needs to be collected in a more efficient way.[31]" (Stromen 2000f)

As a matter of fact, several initiatives are discontinued due to the uncertain availability of resources (-F6) and to the strict emission rules (-F4). Projects that are based only on heat production are too expensive without subsidy. Also, for small-scale combustion plants using waste wood, the strict emission rules lead to high costs due to additional cleaning steps (see Table 8.5 for an overview of discontinued small scale projects) (Kwant and Knoef 2004a).

2002-2004: New Hope

In spite of the failed projects, there are high expectations of an increase in biomass plants with the prospect of a new feed-in tariff system in sight (F4, F5). In 2003, the MEP system is introduced to replace the REB, as the high support level led to high amounts of imported electricity rather than more installed capacity in the Netherlands. However, the expected introduction of the MEP (1 April 2003) is delayed, providing unstable and uncertain investment conditions. The actors in the field are disappointed and angry, as stated in the following quotes:

Table 8.6 Overview of MEP feed-in tariffs (€ct/kWh) (all amounts are nominal and not adjusted to inflation) (Faaij and Juenginger 2005)

Year	Biomass waste incineration efficiency > 26%	Biomass power plants > 50 MWe	Biomass power plants < 50 MWe
2003	6.8	4.8	2.9
2004	6.7	4.0	2.9
2005	9.7	7.0	2.9
2006 & 2007	9.7	6.0	3.6

Platform Renewable Energy proclaims: "the delay is disheartening for investors in renewable energies[32]"; Essent calls it "a first-rate mockery. The government makes a laughing stock of the sector which has good intentions and wants to invest[33]" (DE 2003b-a; DE 2003d)

In addition to the delay, 'Platform Bio-energy' also disagrees with the way the MEP is set up. The Ministry of EZ establishes a duration period of three years, as the price of biomass fluctuates considerably (Stromen 2003d). The Platform disagrees and requires a duration period of ten years for large-scale plants to be profitable, as their pay-off periods are considerably long. Furthermore, the sector in general wants more security about the duration of compensation per kWh (F7). In addition, the Platform requests the rates to be established three years before the start of a project (DE 2003f-b).

In the meantime, energy firm Essent fears for its biomass projects, since it is more profitable to import green electricity from abroad than to produce it in the Netherlands, as long as the MEP is not introduced (DE 2003b-a; DE 2003d).

Finally, in 2004, the Ministry of EZ extends the period of remuneration for biomass plants to a period of ten years (see Table 8.6 for an overview of MEP rates), which leads to a cautious increase in biomass energy plants (Stromen 2004q).

Thus, the lobby activities of the Platform and the sector (F7) are successful, realising a change in institutional conditions. This demonstrates the importance of creating advocacy coalitions by the actors in the field, in order to create sufficient influence to bring about changes in their advantage.

Below, the influence of the MEP on the evolution of several biomass projects is described.

'BioEnergie Twente', 2001 – Ongoing

In 2001 BioEnergie Twente[34] starts a project to convert demolition wood and to produce renewable energy (F1). An engineering firm, Optimum, is commissioned to compare the feasibility of combustion and gasification. Combustion (small-scale grate firing) is the winner, since it is reliable and proven in contrast to gasification (F2). However, as the promised introduction of the new MEP rates is delayed, the project becomes economically unfeasible and, as a result, temporarily suspended (-F4). However, as soon as the new rates are introduced in 2004, the project is continued; the construction lasts from April 2005 until February 2006. In June 2006, the plant is connected to the grid, where 17 ktons of waste wood are converted on a yearly basis to 14 million kWh, providing electricity for 4,300 households (Brugh 2006; Havermans 2006).

Main success factors of this project are the favourable technical aspects and the formation of a market to sell green electricity (F5). Combustion is a reliable and proven technology that increases the confidence and support of entrepreneurs and investors. Furthermore, due to the MEP (F5), the project becomes economically feasible and entrepreneurs have the security that the pay-off time of the plant will indeed be fulfilled.

'Biomass Energy Plant Sittard – BES', 2005 – Ongoing
Another plant that could profit from the MEP feed-in tariff system is the BES in the city of Sittard. Since the end of 2005, the BES is operational, producing 4MW of heat. The electricity production is expected to start in late 2006, as the turbine still has to be placed; 1.2 MWe will be produced and delivered to the 10 kV electricity net of Essent. Initiator is Ms Monique Aarts (F1), director of a gardening business, incited by the increased environmental awareness to reduce CO_2 emissions and to produce renewable energy, and by the favourable institutional conditions, such as the MEP (F5) and CO_2 reduction subsidy (F6). The technology is provided by an Austrian firm as turnkey, based on the bubbling bed principle (F2) (Aldavia 2006; KiviNiria 2006).

Driving forces of this project are the formation of a market (F5), ensuring the project's economic profitability and the availability of the technology as turnkey (F2). This eliminates any technical problems and increases the support of investors (F6). Furthermore, by delivering the electricity to Essent and the heat to the local heating net, a market is guaranteed for this technology (F5).

'Biomass Plant Hengelo – BEC', 2004 – Ongoing
In 2004, waste-processing firm 'Twence' develops plans to construct a biomass plant (BEC) on its industrial site. In late 2004, the environmental permits are applied for and halfway 2006, the construction is started. The plant is expected to be operational in 2006, with a capacity of 15MW where waste wood is combusted[35] (Stromen 2004g; Daey Ouwens 2005b).

In the following table (Table 8.7), an overview of the above-described plants is provided.

To summarise the driving forces of the projects, once again, the most decisive factors are the formation of a market (F5) for green electricity and favourable feed-in tariffs encouraging entrepreneurs to set up biomass combustion plants (F5). In addition, turnkey technology (F2) and the availability of biomass (F6) ensure the commitment of entrepreneurs and investors.

Table 8.7 Overview of stand-alone biomass combustion plants in the Netherlands 2001-2005

Year	Plant	Combustion concept	Biomass capacity (MWe/year)	Estimated electricity production (100% capacity, GWh)	Fuel (estimated amount in kton)
2001	Goor Cogas	Grate firing	1.7 (in 2006)	14	17 Waste wood
2004	Hengelo BEC	Grate firing	15 (in 2006)	131.4	n.a. Waste wood
2005	Sittard BES	Bubbling bed	1.2 (in 2005)	10.5	140 (in 2008) Organic, woody waste
Total				156.8	

In the final paragraph, an overview of the most recent events on system level are provided, as an illustration of the influence of institutional changes.

2005-2006: The End?
In 2005, a deficit of the annual MEP budget incites Minister Brinckhorst of the Ministry of EZ to decide that newly built installations and large bio-energy projects will no longer receive feed-in tariffs between 2005-2007 (Faaij and Juenginger 2005). In spite of this measure, the budget deficit remains unsolved and in August 2006, Minister Wijn of the Ministry of EZ (replacing Minister Brinkhorst), suddenly and without unannouncement, discontinues the MEP feed-in tariff system (-F4) (Blijker 2006; Handelsblad 2006; Uffelen 2006). As a result, new biomass projects are no longer entitled to MEP feed-in tariffs; projects submitted before 18 August 2006 will be concluded and current projects are entitled to the MEP feed-in tariffs for their ten year period. Thus, several projects worth half a billion Euros and with a capacity of app. 100MW will not be implemented (Blijker 2006; Handelsblad 2006; Uffelen 2006).

In addition, recently started projects fear for their continuation, as Mr Van Hutten, manager Renewable Energy, Environment, and Innovation of Cogas, Twente, comments:

> "We definitely need the MEP; without this subsidy, the Goor plant will not be feasible[36]" (Havermans 2006)

Minister Wijn's measure is dramatic, investors withdraw (-F6) (Brugh 2006). For years, the energy sector has been complaining about the inconsistency of the government, yet nothing is changed to provide more continuity. As Mr van Severt from Econcern states:

> "Let's call it a halt in the Netherlands. It is always the same with the Dutch government: all or nothing[37]" and "This is a disaster for the investment climate; this sector needs continuity[38]" (Brugh 2006)

According to the 'Interprovincial consultancy agency'[39] (IPO), the government does not announce a change or discontinuation of the MEP subsidies in between time periods.

> "In less than no time, the Minister helps to destroy the carefully built-up support and confidence of investors[40]" (Brugh 2006)

Official reason for cutting the subsidies is the government's belief that the renewable energy goals of 9% by 2010 will be reached with the currently installed capacity and that, therefore, no more plants are needed. However, critics say that the reason for discontinuing the MEP feed-in tariff system results from the deficit, which is typical for the kind of policies and strategies made by the government on environmental and renewable energy issues (Volkskrant 2006). The subsidy is introduced as green electricity, which is more expensive than grey electricity, but the initial enthusiasm of the Ministry of EZ surpasses the actual estimate and shortly after the subsidy's establishment, it has to be cut down and eventually even terminated (-F4) (Volkskrant 2006). This leaves several unrealised and stranded projects, and investors become reluctant to set up projects if their income is not guaranteed (-F6) (Volkskrant 2006). The fundamental problem

Table 8.8 Overview of key activities per System Function per technology

System Functions	Co-firing		Gasification		Stand-alone combustion	
	Positive	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**
F1:	1131 GWh in 2004, 8 plants		1 large scale plant	1 large-scale plant not realised	197 GWh in 2004, 7 plants	7-10 small-scale plans failed
F2: Knowledge Creation	Technical problems are quickly solved		Desktop research, lab-scale experiments on gas cleaning		Technical problems quickly solved, turnkey technology	
F3: Knowledge Diffusion	Workshops, conferences		Workshops conferences study trips		Workshop, conferences	
F4: Guidance of the Search	White Papers, NMP, MAP, emission rules, biomass classification list	Contradictory emission rules, no uniform biomass and waste definition, tedious permit procedures	High expectations, EWAB and NOB programme, Third White Paper on Energy	Inconsistent government policy liberalisation of the energy market	Ban on combustible waste, increased costs for waste processing, Third White Paper on Energy	Strict emission rules, MEP delayed and uncertain, MEP removed
F5: Market Formation	Coal covenant; MEP	/	/	No niche market, immediate large-scale electricity production	Exemption from REB, CO_2 reduction plan, MEP, 'green' electricity market	REB favours green electricity import; Irregular availability of MEP
F6: Resource Mobilisation	Financial resources from European (EU-APAS) and Dutch research programmes (CO_2 reduction)	No product standard, supply unpredictable, no biomass/ waste market	National research programmes (EWAB, NOB)	Unreliable biomass supply	Biomass surplus, research programmes	Insufficient local fuel
F7: Advocacy Coalition		Resistance of environmental groups and local residents due to feared increased emissions, uncertainty about biomass and waste categorisation	Strong technology push	Reluctance to take risks due to liberalised energy market and unproven technology unproven	Environmental groups and local residents involved in projects, entrepreneurs and investors supportive as technology is proven	

System Functions	Co-firing		Gasification		Stand-alone combustion	
	Positive	Negative	Positive	Negative	Positive	Negative
Technological Factors	Little technical alternations needed, plants, infrastructure, and customers are already present		Very efficient but unproven, high-risk, expensive, little experience and expertise		Proven, efficient, more expensive than co-firing but cheaper than gasification, energy efficiency can be increased by technical alternations	

is the government's lack of long-term vision on what it wants to achieve and with which instruments it wants to achieve its goals (Volkskrant 2006). Consultancy agency Roland Berger describes the Dutch government as follows:

> "The Dutch government displays little vision with respect to the long-term energy supply. Instead of focusing on energy saving, renewable energy production, and CO_2 reduction, they are busy with the mechanisms of the market and the customer's freedom of choice. Instead, the development of a long-term policy for renewable energy is of strategic importance[41]" (Volkskrant 2006)

Minister Wijn's measure leaves the energy sector in confusion and uncertainty. At this moment in time, it is difficult to predict how biomass combustion will further evolve.

8.3 Functional Analysis

In this paragraph, the three technologies are compared, based on the fulfilment of the System Functions. The table below provides an overview of the key activities that occurred per System Function for each technology (see Table 8.8).

1990-1995
The initial trigger is the government guidance (F4) to reduce the national energy consumption. This stimulates energy firms to take responsibility contributing to this resolution and to provide an Environmental Action Plan (see Figure 8.3 Activity pattern of Guidance of the Search) in which they agree with the government that the energy sector will reduce their CO_2 emissions and energy consumption (F5). One of the most obvious options is to replace coal by biomass and to have it co-fired in the electricity plant. This is the first step towards the formation of a niche market for renewable energy (F5). Simultaneously, experiments are carried out with other technologies such as stand-alone biomass combustion and biomass gasification (F2). Thus, in the mid 90s, several projects are developed for co-firing, combustion, and biomass gasification (see Figure 8.1 Entrepreneurial Activities between 1994 and 1996). In this figure, the number of projects per year are represented; the positive lines indicate the start of the projects, whereas the negative lines indicate the end of the projects.

For co-firing and biomass combustion, the teething trouble of the technologies in the first few years are relatively quickly solved[42], due to a wide range of studies (F2) (see Figure 8.2: Knowledge Creation and Knowledge Diffusion) and, as a result, most of the coal plants apply for permanent co-firing permits and four stand-alone combustion plants are constructed between 1995 and 1997 (see Figure 8.1). However, for gasification, the technical problems persist, which is one of the factors resulting in the failure of biomass gasification. As the technology fails to prove itself, all expectations and support collapse and no more activities are developed. In this case, no time and space are allowed for trial and error for the technology.

For biomass co-firing and biomass combustion, this sequence of events can be represented by the following virtuous cycle: Guidance of the Search (F4) to reduce CO_2 emissions and to increase renewable energy production triggers the creation of a market for renewable energies (F5), as the energy sector agrees to contribute. This leads to research for new technological options (F2). As technological problems are resolved, entrepreneurial activities (F1) are developed by applying the technology on a large scale or by constructing new plants. As these activities are carried out in line with the agreements between government and energy firms, financial resources in the form of subsidies or tax exemption are provided (F6) (see Figure 8.5).

1995–2000

In the following period, the production of renewable energy is further incited by the publication of a Third White Paper on Energy and by the liberalisation of the electricity market (see Figure 8.3). For co-firing, a market for green electricity is created (F5), as households can choose their renewable energy provider from 2001 onwards. However, for biomass combustion this has an averse effect, as the import of green electricity is more profitable (-F4). For biomass gasification, the timing is unfortunate, as the technology is not proven yet and still quite expensive. As a result, energy firms are reluctant to take risks on a liberalised energy market and, therefore, turn their back on this renewable energy option (-F1).

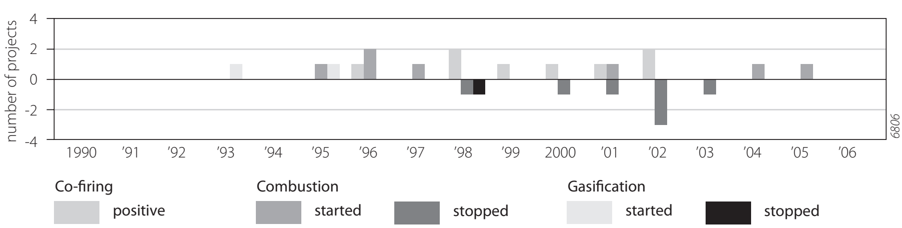

Figure 8.1 Activity pattern of System Function 1: Entrepreneurial Activities

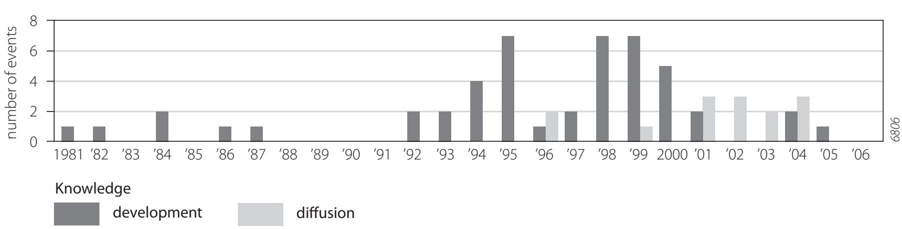

Figure 8.2 Activity pattern of System Function 2 and System Function 3: Knowledge Development and Knowledge Diffusion

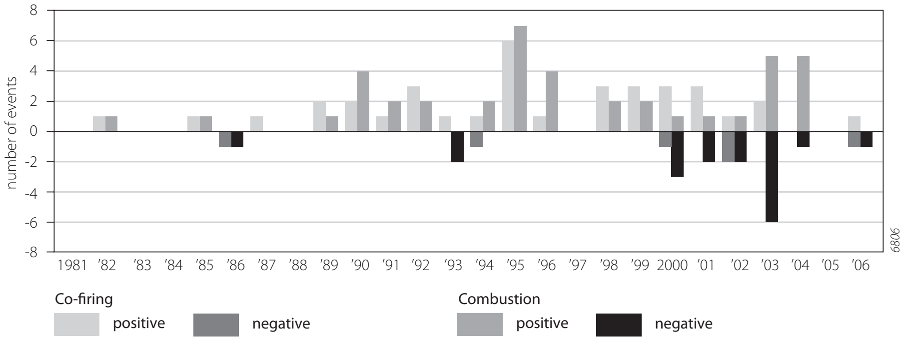

Figure 8.3 Activity pattern of System Function 4: Guidance of the Search

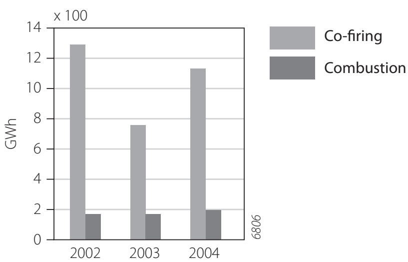

Figure 8.4 Overview of electricity production of co-firing and stand-alone combustion

The foregoing clearly shows that the timing of institutional changes is very important. In the case of biomass gasification, the technology is not ready to compete on a turbulent market, whereas both co-firing and combustion do not need to fear, as the technologies are proven. However, no drastic increase in biomass combustion plants occurs due to unfavourable institutional conditions that make the conditions for biomass plants still not ideal (see Figure 8.1: no stand-alone combustion plants constructed between 1998-2003).

2001-2006

This period is marked by the introduction of several market formation instruments, such as the coal covenant between the Dutch Ministry of Environment and energy firms to further reduce CO_2 emissions, and the MEP feed-in tariff system, where producers are remunerated for the production of green electricity (F5, see Figure 8.4: capacity installed of co-firing and combustion, 2002-2004). As a result, most of the coal plants increase their share of biomass and several initiatives are started to construct additional stand-alone biomass combustion plants. It is especially evident that, due to the introduction of the MEP system, the construction of more stand-alone plants are planned, since this system guarantees a long-term income for those plants. However, as the introduction of the MEP is delayed in 2003, reduced in 2005 and then terminated in 2006, only few initiatives are successfully completed.

Here, the interaction between the System Functions can be described by the following sequence. Specific guidance (F4) leads to market formation (F5), leading to entrepreneurial

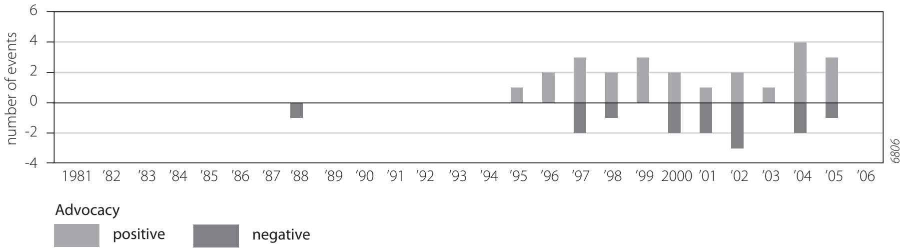

Figure 8.5 Activity pattern of System Function 7: Advocacy Coalition

activities (F1). However, as the guidance remains inconsistent (-F4), the market formation is unstable (-F5) and, as a result, entrepreneurial activities are promptly discontinued (-F1) as no stability and profitability are guaranteed. Once again, we witness the importance of changes in institutional conditions, influencing the fulfilment of the System Functions.

8.4 Conclusion: The System Functions that matter

We applied the System Functions approach to gain more insight into the dynamics of the Biomass Technology Innovation System and to be able to compare the evolution of the different technologies. The research question to be answered in this paragraph is:

How can we explain the differences in evolution between biomass co-firing, combustion, and gasification?

First, the evolution of all three technologies starts with the same starting point, observing the build-up of System Functions such as Guidance of the Search (F4), Knowledge Development (F2), Knowledge Diffusion (F3), and Entrepreneurial Activities (F1). This triggers the introduction of biomass co-firing in three coal plants and the construction of four stand-alone biomass combustion plants plus one gasification plant.

However, a change in the institutional conditions (i.e. liberalisation of the energy market) results in the divergence of the three technology trajectories.

The institutional change has least effect on biomass co-firing, as the Technological Innovation System is already in place and little technological problems are present. In addition, due to the lobby activities (F7) of the system actors, favourable institutional conditions (F4) plus a market are created (F5), resulting in a prompt diffusion of biomass co-firing.

However, the institutional change results in the collapse of the Biomass Gasification Innovation System, as it is still in an early formation phase and the system has not built up enough momentum yet to counter and withstand such a change. In this case, the main reason for failure is the lack of niche market formation, where time and space are provided for trial and error.

In the case of biomass combustion, the Biomass Combustion Innovation System does not quite manage to move on to large-scale diffusion. The system is ready to go, yet the last trigger to make it succeed is missing, i.e. market formation. Only after the introduction of the MEP, a market for green electricity is created (F5), stimulating the setup of plants (F1). However, the moment the market is removed (-F5), entrepreneurial activities collapse (-F1).

Thus, in order to achieve implementation, consistent and long-term government guidance is needed (F4), enabling the formation of a market (F5) that, in its turn, stimulates entrepreneurial activities (F1). Thus, as long as this interaction is not stimulated, the Biomass Combustion Innovation System will not acquire sufficient momentum to reach a breakthrough.

Notes

1 A paper version based on this chapter has been submitted to the International Journal of Technological Innovation, Entrepreneurship and Technology (Technovation)

2 In Dutch: 'Zorgen voor Morgen' – 'Concern for Tomorrow. A National Environmental Survey, 1985-2010' by the 'National Institute for National Health and for the Environment' (RIVM)

3 In Dutch: Nationaal Milieubeleidsplan (NMP, 1989)

4 In Dutch: Nota Energiebesparing (1990)

5 In Dutch: Milieu Actieplan (MAP-I)

6 In Dutch: Vervolgnota Energiebesparing

7 The results of the final report of EnergieNed show that, in ten years time, 17 million tons of CO_2 have been reduced and that, furthermore, less SO_2 and NOx have been emitted (EnergieNed 2000).

8 In Dutch: Ministerie van Verkeer, Ruimtelijke Ordeningen en Milieu (VROM)

9 BEES A: Besluit emissie-eisen stookinstallaties milieubeheer A, 'Order for Emissions to Air from Waste Combustion', passed on 10 April 1987. It sets emission regulations for large-scale incineration plants in industry, refineries, and electricity plants with a thermal capacity of more than 20 MW.

10 Richtlijn Verbranden: 'Directive for Combustion', to prevent air pollution from the combustion of waste in new and existing plants.

11 EWAB, Energiewinning uit Afval en Biomassa (1989-2000) 'Energy Production from Waste and Biomass'; aim is the application of waste and biomass for electricity production.

12 NOH, Nationaal Onderzoeksprogramma Hergebruik afvalstoffen (1990-1997) 'National Research Program for the Reuse of Waste'; aim is to reduce waste and to stimulate reuse by research and development.

13 Tienjaarprogramma Afval (1992-2002) 'Ten Years Waste Program'; provides guidance for the planning and organisation of waste reduction in the Netherlands.

14 Thermie – (1990-1994) 'Non-nuclear Energy RTD Program'

15 Joule – 'Non-Nuclear Energy Research Program' (1991-1994); development and testing of safe, environment friendly, and economic energy technologies, better conversion and use of energy; greater use of renewable energy in Europe's energy supply.

16 A Dutch institution controlling electricity production, transport, and import in the Netherlands and involved in planning new power plants. In 2001, after the liberalisation of the energy market, it was discontinued.

17 The BEES-A regulation is valid for electricity plants larger than 300 MW and for electricity plants co-firing biomass (with a maximum of 10% and a minimum of 25,000 tons per year). Furthermore, if biomass is classified as waste, the BLA standard has to be applied (DE 1998n). The BLA standard prescribes the emission of plants converting waste. This regulation applies if a bio-energy plant converts substances classified

as waste. On the other hand, if the biomass is not classified as waste, the NER is valid. This standard is not obligatory, but should be used as line of action by the permit provider (DE 1998n).

18 "In terms of reconfiguration processes, this mechanism implies the physical connection of new technologies with old technologies. Upon improvement of the new technology or change of circumstances, the new technology may gradually develop into a more hybrid phase or into an independent technical form" (Geels 2002).

19 This description is based on chapter 6, Biomass Gasification in the Netherlands, 1980-2004.

20 In the biofuels sector, a distinction can be made between first generation (1G) and second generation (2G) biofuels. 1G fuels include a conventional set of conversion technologies with limited performance in terms of costs and CO_2-reduction, yet already in a near-commercial stage of development. Examples are bio-oils, bio-ethanol and biogas. 2G biofuels consist of a variety of technologically complex options, of which, although still in a pre-commercial stage, high performances are expected. The idea is to convert woody biomass (forestry products and waste) into biofuels. Products are Fischer-Tropsch bio-diesel, pyrolysis bio-oil, or biocrude that can be used to replace diesel (Hamelinck 2004; Jonasson et al. 2006).

21 In 1992, during the Environmental and Development Conference in Rio de Janeiro, the industrial countries agree to reduce their CO_2 emission by 2000 to the levels of those in 1990 (EnergieNed 2000).

22 In Dutch: Derde Energie Nota (EZ 1995).

23 In Dutch: Regulerende Energiebelasting.

24 In 1997, the Dutch government reserves 681 million Euros for the realisation of this climate change policy, where 425 million Euros are destined for the stimulation of investment projects (SenterNovem 2005).

25 The Netherlands aim for an annual reduction of 40 Mtons of CO_2-equivalents by 2010, of which half will have to occur in the Netherlands and the other half abroad.

26 See the case of the Amer plant in 1996, where the waste wood is sold to Sweden since this is more profitable than having it processed in the Netherlands and then converted to energy (Chapter 6).

27 The oven melted before the necessary temperature was reached, causing the generation of insufficient steam pressure and, thus, the production of insufficient electricity (Novem 2003).

28 Total investments are 2.25 million Euros; Novem provides 450,000 Euros.

29 In Dutch: "Uit ons vooronderzoek bleek dat de vergassingstechnologie op zich haalbaar zou zijn. Maar de combinatie met een gasturbine voor elektriciteitsopwekking was dermate onzeker dat we daar niet mee uit de voeten konden. Ons doel is de installatie in 2000 operationeel te hebben. Dat moet ook wel, willen we dan de doelstellingen kunnen halen voor elektriciteitsproductie uit duurzame bronnen – 2.8% van het totaal."

30 Dutch research and consultancy organisation

31 In Dutch: "Nu al kan een installatie als Lelystad (1.3 MWe) financieel niet uit (vanwege de NOx-eisen). Om BM als DE bron te stimuleren, zijn meer subsidies voor deze installaties nodig of moet resthout efficient ingezameld worden." (Stromen 2000f)

32 In Dutch: "…demotiverend voor de investeerders in duurzame energie".

33 In Dutch: "..een aanfluiting van de bovenste plank. De sector, met alle goede voornemens en investeringen in Nederland, wordt daarmee gewoon voor de aap gezet".

34 A consortium consisting of Bruins & Kwast (Dutch organic waste recycling firm), Cogas (Dutch gas firm) and participatiemaatschappij Oost Nederland

35 Due to time restriction, the development of the plant cannot be further documented, as the analysis stopped in August 2006.

36 In Dutch: "We hebben die MEP keihard nodig, zonder subsidie zou de centrale in Goor niet rendabel kunnen draaien" (Havermans 2006)

37 In Dutch: "Laten wij in Nederland maar stoppen, want het is altijd hetzelfde met de overheid. Hollen of stilstaan." (Brugh 2006)

38 In Dutch: "Dit is een ramp voor het investeringsklimaat. Deze sector heeft continuïteit nodig"(Brugh 2006)

39 In Dutch: "Inter Provinciaal Overleg (IPO)"

40 In Dutch: "De minister helpt nu in een handomdraai het zorgvuldig opgebouwde draagvlak en het vertrouwen van investeerders om zeep" (Brugh 2006)

41 In Dutch: "De Nederlandse overheid legt te wenig visie aan de dag waar het de energievoorziening op lange termijn aangaat. In plaats van na te denken over energiebesparing, de opwekking van duurzame stroom en de uitstoot van broeikasgassen is Nederland vooral bezig met marktwerking en keuzevrijheid voor de consument. Terwijl het ontwikkelen van een langetermijnbeleid voor duurzame energie van strategisch belang is."

42 Furthermore, app. 4-5 years of trial and error are needed for co-firing and stand-alone combustion before they become reliable technologies, as most of the projects show upon comparison of the time span between construction and actual electricity production.

9 Methodological Results

In this paragraph, the insights related to the System Function approach and event analysis applied to the case studies are discussed and answers to the first two research questions are provided.

RQ 1: How can the process study approach be applied, in order to analysee System Functions and the dynamics of Technological Innovation Systems?

The process study has been applied to analyse the dynamics of the Technological Innovation System. A historical analysis based on events has been carried out, where the events are retrieved from literature sources such as newspapers, professional journals, periodicals, websites, reports, and documents (step 1). They are ordered chronologically into a database and, subsequently, allocated to the System Functions (steps 2 and 3).

These literature sources have proven to be reliable sources of information, since they document a large variety of event types in a systematic and thorough way (i.e. periodicals are available every 2-3 months). The professional periodicals, such as Afval!, Biovisie, Duurzame Energie, Energie- en MilieuSpectrum, Energie Consulent, and Nieuwsbrief Energie- en Samenleving, provided a diverse assortment of events, such as workshops, research programmes, project descriptions, institutional conditions on detailed or general level, as well as insight into political games, lobby activities, and R&D activities. The events retrieved from the LexusNexus database provided a wide variety of events on a national level, but also entrepreneurial activities on a local level. The combination of those different literature sources complemented each other with respect to detailed and general events, and was used for the triangulation of the data, since several sources reported the same events. It is acknowledged that more events exist and that some may have been excluded by this method. However, in selecting events, a balance had to be established between completeness and workability. In this case, the set of 1774 events is a valid compromise. Nonetheless, to make sure that no crucial events are missing, interviews were carried out with experts in the field to fill any gaps (step 7).

With respect to graphical representation (step 4), it is found that, for some System Functions, the amount of events is too small to provide useful and illustrative graphical patterns. However, this does not imply that the corresponding System Functions are not important. On the one hand, it could be said that, for some System Functions, a limited number of events is just as important as many events for others, yet on the other hand, if only a minimal amount of events is present, graphical representations are not suitable. An example is Market Formation, where tables containing feed-in tariffs per year per technology proved to be more useful. An additional way to illustrate a System Function is the use of quotes, which has been used for Advocacy Coalition and Guidance of the Search, when actors in the field expressed their expectations, support, or rejection of the technology or the Technological Innovation System.

Finally, the graphical activity patterns of the System Functions proved to be useful in supporting the narrative (step 6). The graphical representations helped to identify crucial breaking points (i.e. liberalisation of the energy market) where several activity patterns showed a collapse (i.e. for biomass gasification). In addition, the individual functional patterns show the growth or collapse of a System Function, which turned out to be helpful in identifying crucial events within the narrative that can explain such trends. However, the activity patterns do not provide an explanation with respect to the causal relations and the interactions between the System Functions. Those relations can only be identified by combining the empirical material with interviews.

Based on the events (step 5), a narrative was constructed describing the dynamics of the Technological Innovation System in terms of related flows of events. However, the design and interpretation of the narrative is strongly influenced by the author. Therefore, also the narrative is verified with experts (step 7). The advantage of using literature data to reconstruct the storyline and testing it with experts in the field, rather than basing it solely on longitudinal interview data, is that the author's bias and the interviewees' retrospective bias are reduced.

One of the aims of this thesis is to demonstrate whether the set of System Functions developed at Utrecht University is complete and useful. An answer to the second research question of this thesis is provided below.

RQ 2: How suitable is the set of System Functions to describe and analyse the dynamics of the TIS?

The set of System Functions proposed in Hekkert et al. has been applied to structure the empirical data of the four biomass case studies.

It is expected that, if a considerable amount of events is difficult to allocate to either one of the seven System Functions, it is a clear indication that the list of System Functions is incomplete. The table below (Table 9.1) provides an overview of the number of events per System Function and additional categories that could not be allocated to the System Functions (step 3).

Of the total amount of 1774 events, there are 806 events that could not be allocated to the System Functions. However, this category of events falls under the category of context as described in Chapter 3 and represented in Table 3.2. This category consists of events that are either listed double (see event numbers 9 and 10 in Table 3.2), or that represent changes that are external to the Innovation System (event number 19), general descriptions about renewable energies (event number 18), or technical characteristic (event number 12). These events are not allocated to the System Functions and are not represented in the graphical representations. They serve as background information for the narrative. Thus, all events are either allocated to the System Functions or fall under the category of context. A careful re-examination of the 800 events did not lead to additional System Functions. Therefore, the list of System Functions used in this thesis seems to be an excellent starting point for explaining the dynamics of emerging Technological Innovation Systems.

If only a small number of events would relate to a specific System Function, this System Function might not be relevant to understand technological change. However, from Table 9.1 it can be deduced that several events are allocated to each System Function, leading to the conclusion that no System Function seemed irrelevant.

Table 9.1 Overview of number of events per System Function

System Functions	Event categories	Sign	Total number of events
Function 1: Entrepreneurial Activities	Project started	+1	111
	Project terminated	-1	-49
Function 2: Knowledge Development	Desktop/Assessment/Feasibility studies on the technology	+1	183
Function 3: Knowledge Diffusion	Workshops, Conferences	+1	21
Function 4: Guidance of the Search	Positive expectations of the technology; Government regulations	+1	240
	Negative expectations of the technology; Expressed deficit of regulations	-1	-93
Function 5: Market Formation	Specific favourable tax regimes and environmental standards	+1	48
	Expressed lack of favourable tax regimes or favourable environmental standards	-1	-15
Function 6: Resource Mobilisation	Subsidies, investments for the technology; Biomass streams allocated to the project	+1	57
	Expressed lack of subsidies, investments; Shortage of biomass streams allocated to the project	-1	-36
Function 7: Advocacy Coalition (Creation of legitimacy/ counteract resistance to change)	Lobby activities for the technology; Support of technology by the government, industry	+1	78
	Lobby activities against the technology; Expressed lack of support by the government, industry	-1	-37
Total number of events allocated to System Function			968
Total number of events not allocated to System Functions	Context and Doubles (Technology description, general information, exogenous activities to the TIS)		806
Total amount			**1774**

Nonetheless, there is a difference in the number of events allocated to each System Function, see Entrepreneurial Activities, Knowledge Development, and Guidance of the Search, compared with Knowledge Diffusion, Market formation and Resource Mobilisation.

For Knowledge Diffusion, the small amount of events does not indicate that this particular System Function is irrelevant. On the contrary, it demonstrates that the Technological Innovation Systems studied are still emerging and malfunctioning, resulting in a lack of events. However, on the other hand, events that fall under Knowledge Diffusion are also quite difficult to retrieve from an archive-based analysis. Other methods, such as interviews, would shed more light on the processes of knowledge diffusion. In the cases of biomass digestion and gasification in the Netherlands, research and entrepreneurial activities are scattered and hardly any collaboration and knowledge diffusion is observed, that could lead to an improvement of the technology.

Several feasibility and other studies are carried out and even repeated by various actors, but the application of knowledge and technological improvements are lacking throughout the years. Once again, this shows that Knowledge Diffusion is a relevant System Function; however, the archive-based method is not ideal for measuring this System Function.

Furthermore, for Market Formation, a low amount of events is collected. It could be argued that only few events are needed, due to their high impact. However, the cases showed that market formation is mostly missing, resulting in a hampered breakthrough of digestion, gasification, and combustion technology due to a malfunctioning Technological Innovation System. However, once a market formation instrument is introduced, such as a feed-in tariff system (i.e. EFA and EEG in Germany, and MEP in the Netherlands), a clear increase in entrepreneurial activities is observed and the diffusion of biomass digestion in Germany and biomass combustion in the Netherlands sets off. Thus, in this case, only few events are needed for Market Formation, due to the high impact of such events.

In addition, for Resource Mobilisation few events occurred. However, the low amount cannot be ascribed to the System Function being irrelevant but, instead, to the malfunctioning of the Technological Innovation System. Throughout the biomass digestion and gasification case studies, several events occurred where the government withdrew subsidies or where actors expressed a lack of resources, financial as well as physical (i.e. biomass). Thus, the System Function of Resource Mobilisation is crucial as well, yet, due to the malfunctioning Innovation System, only few events occured.

Furthermore, some events can be allocated to two System Functions. An example are workshops, that can be classified under Knowledge Diffusion, but the content of the workshop – if expectations of the technology are expressed – can be classified under Guidance of the Search. There are several other such examples where the text includes several events that can be allocated to several System Functions. Only repeated close reading and interpretation can ensure that all events are identified and allocated to the corresponding System Function or categorised as context.

All in all, the set of System Functions proved to be useful in structuring and analysing the data. In addition, all System Functions proved to be relevant and no additional System Functions were found within the context category. The lack of events for Market Formation and Resource Allocation could be mainly attributed to the malfunctioning of the particular TIS. The only doubt remains about Knowledge Diffusion, whether, by means of another methodology, more events would have been retrieved or, instead, this System Function could be combined with Knowledge Development as has been done recently by Bergek and Jacobsson (Bergek et al. 2006).

A final remark about the added value of studying technological changes using the System Functions approach is the following. The description of activities provided additional insights, compared with earlier empirical studies using a different framework. In studies in which the Strategic Niche Management concept is applied to the evolution of biomass technologies, the importance of structural factors such as changes in the socio-technical landscape (for example the change in oil prices) and a mismatch in rule sets (for example the lack of co-digestion regulation) are highlighted. The same structural factors were highlighted with the System Functions approach. However, on top of this, the functional analysis showed the effect of these structural factors on the activities in the system and, furthermore, it showed that these structural factors were, subsequently, influenced by a lack of coordinated activities in the Biomass Innovation Systems. Hereby, we gain understanding of the interplay between structural change of the institutional structure and the activities in the Innovation System.

Finally, analysing troublesome stories in terms of System Functions allowed comparison with more successful cases. Thus, we can comprehend how functional patterns differ in troublesome and successful processes of technological change, and we can study the difference in interplay between institutional framework and Innovation System activities. This is useful information when the aim of policy making is to contribute to well functioning Renewable Energy Innovation Systems.

10 Conclusions and Discussion

In this chapter, answers to the research questions of this thesis are provided; lessons learned from the case studies will be highlighted. The paragraph will be concluded with policy recommendations.

10.1 Answers to Research Questions 1 and 2: Methodological Issues

The first question of this thesis is:
RQ 1: How can the process study approach be applied in order to analyse System Functions and the dynamics of Technological Innovation Systems?

The process study, as designed by Van de Ven and collegues (1999) was adapted and applied to analyse the dynamics of four Biomass Energy Innovation Systems. Where they followed innovation projects in real time, the analysis in this thesis is based on historical data. This resulted in the 8-step approach as described in Chapter 3. As with the Minnesota studies, the 'event' was used as key unit of analysis. The first step was to retract as many historical events as possible from literature sources and to list them chronologically into a database (steps 1 and 2). The literature sources used were professional energy journals and a digital database called Lexus Nexus. These sources proved to be quite useful in retrieving historical events. The Lexus Nexus database contained all Dutch national and regional newspapers from 1990 onwards. Especially the regional newspapers provided much information about local entrepreneurial activities. Using this database proved to be very efficient, since information was digitally available and could, therefore, be easily transferred into the database. Furthermore, professional journals dealing with (sustainable) energy were used. These journals were considerably important for providing data on the first time period (1980-1990) of the analysis, since Lexus Nexus contains data from 1990 onwards. The professional journals were quite useful for gaining insight into the political games, lobby activities, and R&D activities. The only drawback of using these journals was the absence of digital storage, which resulted in a highly labor-intensive process. Combining professional journals and general newspapers allowed triangulation of the data; furthermore, it proved to give a thorough overview of what happened in the Innovation Systems over time. The interviews confirmed that no new major events appeared to be missing.

Upon retrieval, the events were classified into event categories, which were then allocated to the System Functions using a classification scheme (step 3) (see Table 3.1). The classification scheme is based on the definitions of the System Functions. It proved to be difficult at times to indicate specific event categories per System Function. The ambiguity in the classification scheme was resolved by iteration between theory and data and intercoder reliability testing.

By counting the events allocated per System Function per year, graphical representations were made (step 4). These graphs represent functional patterns over time, which helped to identify breaking points and the overall trend of fulfilment of the particular System Function. Based on the chronological events, a timeline was constructed, describing the development and changes throughout the years (step 5). Since the events were chronologically ordered in the database, the narrative could be constructed systematically.

By combining the narrative and the functional patterns, the interaction between the System Functions, as well as the causal relation between the events, could be identified (step 6). In order to reduce any possible bias and to verify the completeness and correctness of the narrative, interviews with experts in the field were carried out (step 7).

The 8-step approach proved to be a workable adaptation of the process study approach of Van de Ven and colleagues, in the context of a functional analysis of Biomass Innovation Systems; it contributed to valuable insights into the dynamics of this TIS.

RQ 2: How suitable is the set of System Functions to describe and analyse the dynamics of the TIS?
The process study approach was mainly used to acquire data, whereas the set of System Functions, as proposed in Hekkert et al., was applied to structure the empirical data of the four biomass case studies. Question is whether this set is complete and/or contains superfluous System Functions. The amount and nature of the data collected showed that no System Function was irrelevant (i.e. events were allocated to each System Function) and that no events were found that could represent an additional System Function (i.e. events that could not be allocated to System Function were doubles, external factors, or technical or general information catergorised as context). Thus, the list of seven System Functions proved to be a valid starting point for creating insights into the system dynamics.

Furthermore, the System Functions approach helped to structure the vast amount of data and, by graphical representations, to highlight crucial breaking points within the narrative. The approach helped to map the dynamics of the Biomass Innovation Systems since the characteristics, strengths, and weaknesses of these systems were identified.

10.2 Answers to Research Question 3: Empirical Conclusions

RQ 3: What do functional patterns tell us about the dynamics of Biomass Innovation Systems?

The results from the case studies showed that several functional patterns occurred in the Biomass Innovation Systems. These can be divided into virtuous and vicious cycles that will be described in more detail in the paragraphs below.

Virtuous Cycles
For the biomass digestion case in Germany and for co-firing in the Netherlands, reinforcing cycles are observed, where the System Functions are fulfilled, interact with, and reinforce each other.

The case of biomass digestion in Germany: all System Functions need to be fulfilled
In the case of biomass digestion in Germany, positive interactions between the System Functions lead to the build-up of System Functions. Government guidance (F4) triggers entrepreneurs to create and diffuse knowledge (F2, F3), which results in the setup of the first digestion plants (F1).

Subsequently, lobby activities (F7) start to improve institutional conditions. Shortly afterwards, the government increases the feed-in rates (F4). This leads to a market formation (F5), which results in an increase in constructed plants (F1). These activities trigger yet other System Functions such as Resource Mobilisation (F6) and Knowledge Diffusion (F3) to be fulfilled, resulting in the fulfillment, interaction and reinforcement of all of the System Functions. A virtuous cycle is born. This virtuous cycle overcomes a temporary vicious cycle, when negative guidance (-F4) results in a subsidy budget cut (-F6), leading to a decrease in new projects (-F1). However, this vicious cycle is promptly interrupted by the provision of financial resources (F6) by another Ministry (F4); the construction of plants is continued (F1). Subsequently, lobby activities (F7) ask for better institutional conditions (F4) and in 2004, better feed-in tariffs are introduced (F5). The feed-in tariffs lead to market formation, which results in the final breakthrough of biomass digestion in Germany (F1).

This development and diffusion of the technology occurs in a time span of 10 years, where continuous interactions of System Functions reinforce each other as to build up a virtuous cycle. The build-up is strong enough to overcome a vicious cycle, so that the virtuous cycle continues and a market is formed, which leads to the breakthrough of biomass digestion.

This case shows that technology development is successful when the System Functions are fulfilled, reinforcing each other. However, some critics may say that the case of Germany is merely a subsidy story, where the success is attributed to the large amounts of finances provided by the government, rather than the fulfilment of the System Functions. Yet, our analysis clearly shows that finances and institutional alignment were not in place beforehand. The alignment occurred gradually in the course of several years, due to the build-up of System Functions such as Entrepreneurial Activities and Advocacy Coalitions, that provided a reliable technology and that lobbied for better institutional conditions and financial resources respectively. Thus, this shows that the build-up of a well functioning Innovation System around a technology plays a crucial role for its successful diffusion, as do favourable technical and economic aspects.

The case of biomass co-firing: actors, institutions, and networks are already in place, yet System Functions remain crucial for breakthrough

The case of biomass co-firing is somewhat different, as it has a head start in comparison with the other biomass case studies. For biomass digestion, gasification, and combustion, the Innovation System has to be built up from scratch. In the case of biomass co-firing, the actors, plants, and infrastructures are already in place, being part of the incumbent system. Nonetheless, the dynamics and sequence of events are interesting and do provide lessons for the other case studies. The sequence of events starts with guidance of the government and the energy firms of the incumbent system (F4) to reduce CO_2 emissions, which leads to knowledge development (F2). Co-firing is a very promising option and favourable guidance (F4) and resources (F6) are provided and, as a result, entrepreneurial activities develop (F1). Around 2000, there is a temporary vicious cycle, as the institutional conditions are not fully aligned with the needs of technology and entrepreneurs (-F4), which leads to a delay of projects (-F1). However, due to lobby activities by the energy firms (F7), agreements with the government are finalised (F4). As a result, favourable institutional conditions are provided and a market is formed (F5). This is the final trigger to implement co-firing in all of the coal plants (F1).

One critical note is that the analysis of co-firing is based on an earlier study (Raven 2005) due to time constraints. However, within the scope of identifying the underlying factors that make one technology succeed over another, this case shows that, in spite of the so-called head start, where most of the structural elements were in place (i.e. plants, actors, networks), the System Functions do need to be fulfilled and a Technological Innovation System does have to built up around the particular technology before it can be successfully diffused and implemented. Crucial factor leading to the final breakthrough of the technology is the formation of a market.

To summarise, virtuous cycles occur when several System Functions are fulfilled, interact with, and reinforce each other, thus triggering other System Functions to be fulfilled as well. In both cases, a build-up of System Functions occurs, able to overcome temporary vicious cycles, as has been seen in the two cases described above. In addition, both cases show that the breakthrough could only occur due to the build-up of the System Functions, as a Technological Innovation System has to grow around a technology for it to be strong enough to compete with the incumbent system and to break through on the market.

In the next paragraphs, examples of vicious cycles are illustrated, in which either the System Functions collapse, or no interactions between the System Functions occur, or the System Function crucial for breakthrough is missing.

Vicious Cycles

The case of biomass gasification: the build-up and collapse of System Functions
In the case of biomass gasification, a build-up of several System Functions first occurs in the period 1990-1998, such as Guidance of the Search (F4) triggering Knowledge Creation (F2), Knowledge Diffusion (F3), Resource Mobilisation (F6), and Entrepreneurial Activities (F1) to occur. However, in 1998, a change in institutional conditions (i.e. liberalisation of the energy market) triggers a vicious cycle, where negative guidance (-F4) results in the closure of several projects (-F1), less knowledge creation (-F2), less investments (-F6), less research (-F6), negative expectations (-F4) and, finally, the discontinuation of entrepreneurial activities (-F1). These negative events reinforce each other and, as a result, no more activities are carried out, due to which the system collapses within a couple of years. Ever since then, biomass gasification has failed to become diffused on a large scale.

Main blocking mechanism is the lack of government guidance to provide clear and consistent policies (-F4) and the lack of a market niche (-F5), where the actors could have experimented and built up experience with the technology. At the beginning, the expectations are high that biomass gasification will be the solution, yet due to unsolved technical problems and inconsistent government guidance (-F4), the opinions change drastically as the energy market is liberalised. The liberalisation comes too early for gasification as it is still an unreliable and expensive technology. Apart from the unfortunate timing of the liberalisation, no additional time and space are allowed for trial and error, to solve the technical problems. Investors and government consider the technology unfit and unworthy for further support (-F7), which results in the collapse of the Biomass Gasification Innovation System.

The case of biomass digestion in the Netherlands: no interaction between System Functions
For biomass digestion in the Netherlands, an irregular functional pattern is observed, as positive and negative System Functions seem to take alternative turns every so many years. In the period

1974-1987, the System Functions of Knowledge Development (F2) and Entrepreneurial Activities (F1) occur, yet no other System Functions are triggered. In the following years, negative guidance against biomass digestion (-F4) hinders any market formation (-F5), investments (-F6), or lobbies to occur (-F7). Only in 1989, a cautious build-up of System Functions arises when Guidance (F4) stimulates both Knowledge Creation and Diffusion (F2 and F3) of biomass digestion, resulting in the setup of several plants (F1). However, some System Functions remain unfulfilled, as for instance Market Formation (-F5) and Resource Mobilisation (-F6). These negatively fulfilled System Functions serve as nourishing ground for a vicious cycle to take off in 1995. Trigger is negative guidance (-F4) with respect to biomass digestion, leading to a lack of resources (-F6), forcing several plants to shut down (-F1). The only activities that continue are lobby activities (F7), which do not remain unnoticed by the government (F4). As a result, co-digestion is partially permitted several years later. In addition, the government wants to increase the share of green electricity (F4) and introduces a feed-in tariff system (F5). Finally, biomass digestion can profit from this market formation as well (F5), and an increase in biomass digestion plants occurs in the following years (F1).

In this case, no continuous build-up of System Functions occurs. Some System Functions are fulfilled but they do not interact with each other as to reinforce each other and to trigger other System Functions. This provides a scattered functional pattern that easily collapses in the case of mutual reinforcement of negative System Functions.

The case of biomass combustion: missing the crucial System Functions for breakthrough

For biomass combustion, most of the System Functions are fulfilled and the TIS is built up and almost ready to go, yet the last crucial trigger is missing to cause a final breakthrough. Between 1990-1998, the build-up of a virtuous cycle occurs where guidance (F4) leads to research and knowledge creation (F2), and positive results lead to entrepreneurial activities (F1). However, between 1998-2001, no additional activities are developed, even though biomass combustion is a proven and reliable renewable energy option. This is a result of the lack of market formation (-F5). As a matter of fact, there is a flaw in the tax exemption system, favouring the import of green electricity rather than producing it in the Netherlands. However, in 2003, a feed-in tariff system is introduced by the government (F4), inciting the formation of a market (F5), which results in a setup of projects and plants (F1). Biomass combustion receives a boost as well, as a market is formed and, as a result, entrepreneurs are now willing to set up projects and to construct plants (F1). However, in 2005 and 2006, the government decides that new biomass plants are not entitled to feed-in rates and, as a result, any new and future project plans are put on hold (-F1).

From this case we learn that, in spite of the fact that most of the System Functions are fulfilled and that the technology is proven and reliable, the technology will not break through as long as there is no secure market formation.

General

Other observations that are made across the case studies relate to the specific event sequences, key drivers, and starting points of the virtuous cycles. For the majority of the virtuous cycles, an important starting point seems to be the urgency of the government to comply with national or international goals on energy or climate change (F4), thus triggering research for solutions (F2). In most cases, the sequence Guidance (F4) -> Knowledge Development (F2) is observed. This contradicts the linear model, where technology development should be the starting point of such a sequence. Most of those technologies are 'new combinations' of yet existing technologies, either transferred from another sector (digestion technology was already used in the 70s for wastewater treatment) or used with a different feedstock (coal gasification was used in the second world war as no petrol was available). The event sequence described above also undermines the linear model, as it represents the search processes as 'creative destruction', in which, incessantly, something new is created, destroying the old.

Most of the sequences start off with Guidance (F4) and continue with Knowledge Development (F2). However, the following sequences all differ from each other. There are no more than two identical sequences, since different actors are involved, acting and reacting in different ways. This shows that the dynamics are considerably complex and that there is not merely one ideal development.

However, this does not mean that the development and diffusion of emerging biomass technology cannot be steered or accelerated. Based on the findings of the case studies, crucial triggers for breakthrough have been identified. Key drivers that need to be stimulated to incite diffusion of emerging biomass technologies, are mostly Guidance of the Search (F4) and Market Formation (F5). In several cases, positive guidance (F4) is responsible for an increase in System Functions such as Knowledge Development (F2), Resource Allocation (F6), Advocacy Coalition (F7), and Entrepreneurial Activities (F1). However, a breakthrough does not occur until a market is formed (F5) providing entrepreneurs and investors with a long-term, stable perspective. This is visible in the case of biomass combustion, where guidance (F4) triggers most of the other System Functions to occur and a virtuous cycle is observed. However, the technology does not break through until a market is formed (F5). In those cases where a market is formed – as was the case with biomass digestion in Germany and co-firing in the Netherlands – the technology is diffused in a relatively short period of time (ten years). Thus, if positive guidance and market formation are incited for biomass digestion and gasification in the Netherlands, it can be expected that these technologies will be successfully diffused and implemented as well.

Yet, another aspect that needs to be considered are the technology characteristics. A well functioning, reliable and profitable technology is likely to gather more support and enthusiasm from entrepreneurs, investors, and policy makers than a technology that is expensive and unreliable. Thus, positive technological characteristics will result in an easier fulfillment of the System Functions (i.e. co-firing and combustion where only few technical problems occurred). In other words, the technological characteristics are very important and influence the fulfilment of the System Functions. However, this is valid the other way round as well, as the System Functions influence the technological characteristics (i.e. biomass gasification with no space and time for the technology to further develop and for actors to experiment and to build up experience). For a technology to become reliable and profitable, long periods of trial and error are needed. The Technological Innovation System needs to provide space (a niche market) and resources (investments) for entrepreneurs to experiment with and to improve the technology. If time and space are not provided, the development and diffusion of those technologies will become considerably problematic.

In the case of gasification technology, the latter occurred, as the (theoretically based) expectations were high that the technology would become efficient and profitable. However, in practice, the contrary occurred. The technology proved to be far more complex and unreliable than was expected. Instead of providing a trial and error period, guidance (-F4) and resources (-F6) were withdrawn, resulting in the failure of the technology.

Thus, radical technologies need long time periods for trial and error (more than ten years), and much patience is asked from the Technological Innovation System, policy makers, and other actors to allow and support this period.

10.3 Answers to Research Question 4: Policy Recommendations

In this section, the main lessons are highlighted and handholds for policy makers are provided.

RQ 4: What can we learn from the approach applied and findings obtained, in terms of options to accelerate the diffusion of biomass in particular and renewable energy in general?

General

The lesson learned is that biomass technologies go through a long-term trajectory (10-30 years) of development, diffusion, and implementation. This requires from a government to develop long-term policy goals and to stick to these policies. In other words, what is needed is a reliable and visionary government. Innovation is a time-consuming search process with many risks. Not taking these dimensions of innovation into account is a guarantee for failure. From the biomass cases studied it becomes clear that current policy making too often has a too limited time horizon. Within these long-term policies, ample space should be provided for learning and experimenting for technological problems to be resolved; System Functions need to contribute for this process to occur. This includes providing space for the necessary competences of the actors to develop. Furthermore, it accounts for policy makers who, until now, have too often (implicitly or explicitly) acted from a linear model perspective. They too should acquire the competences necessary to develop more systemic policies.

Influencing Patterns

In the foregoing, we distinguished between positive and negative patterns. Policies with regard to positive patterns (characterized by clear virtuous cycles) are not that difficult to design (However, whether or not they can also easily be implemented is, naturally, a different issue). Yet, when we look at the necessary policies, we conclude that they differ considerably from the policies that are mostly in place at this moment in time. Current policies often focus on financial instruments, whereas our analysis clearly shows that, although finances are indeed important, what is really needed are stable and long-term policies providing a long-term vision (guidance), space for learning and experimenting, and markets. This will allow virtuous cycles to occur.

Looking more specifically at the dynamics of virtuous cycles, it becomes clear that a number of System Functions plays a particularly important role. The influence of Guidance of the Search (F4) is significant in triggering or hampering the further fulfilment of other System Functions. When guidance is negative or lacking, most of the other System Functions remain unfulfilled or they collapse (see biomass digestion and gasification in the Netherlands), whereas the contrary occurs when positive or continuous guidance is provided (see biomass co-firing in the Netherlands and biomass digestion in Germany).

The government plays an important role in providing guidance, but it is not the only party to do so. Entrepreneurs also need to take the guidance process more seriously, for instance by lobbying for favourable institutional conditions (see biomass digestion in Germany, where Unions and Associations have been set up). It goes without saying that, also in this case, a long-term perspective is crucial.

In addition, entrepreneurs should not remain individualistic but 'pack together' (Van de Ven et al. 1999; Van de Ven 2005). This would create a higher impact of their actions, compared with individual entrepreneurs lobbying for better institutional conditions or financial support. (This difference became apparent in the case comparison of digestion in Germany versus the Netherlands where in Germany, Unions were formed to lobby for better institutional conditions, whereas in the Netherlands, the activities remained scattered and uncoordinated throughout the years.) Furthermore, by means of a joint approach, knowledge diffusion would be promoted as actors compete together instead of against each other. From the case studies, it is observed that the Netherlands has excelled in creating competition between different emerging technologies, where system actors such as entrepreneurs, scientists, and policy makers, contributed to the contested nature of technologies. In addition, most of these system actors seemed to be unaware of the fact that tough competition in very early phases of development reduced the chances of survival for most emergent technologies. Therefore, 'running in packs' is a completely different strategy than what has been followed so far in the Dutch renewable energy field. Finally, another advantage of packing together could be that, if numerous entrepreneurial activities are set up, it becomes more difficult for the government to antagonise these entrepreneurial activities by removing subsidies or switching policies.

The case studies reveal yet another crucial System Function: Market Formation (F5). Market Formation proves to be the final trigger leading to the breakthrough of a technology (i.e. biomass combustion in the Netherlands). Due to the lack of a market, the Biomass Innovation System did not manage to move from a development phase to a breakthrough phase. Although entrepreneurs play a crucial role, the government can easily frustrate their activities by means of unexpected switches in policy making.

To summarise

The government should develop (and maintain) long-term oriented and consistent policies, based on an Innovation Systems perspective. Only in such a stable environment, actors (including policy makers) may find the time and incentives to go through the processes of learning and experimenting, necessary for the development of complex Technological Innovation Systems. Based on the analyses of the systems under development, the government should focus, in particular, on removing barriers that hamper virtuous cycles (i.e. inconsistent, contradictory, and unstable regulations) and on developing and stimulating the further development of yet existing virtuous cycles (i.e. market formation, stable and continuous guidance). Thus, the fulfilment of System Functions such as Guidance of the Search and Market Formation plays a crucial role in this context.

Entrepreneurs should also take a more active role and realise that they do not innovate in isolation but in the context of a system. They should get involved in processes of guidance, facilitating knowledge exchange and joining forces to strengthen their lobby activities. They should become the actor that governments can no longer ignore.

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Summary

Introduction

The starting point of this thesis is the problem that the current energy system is largely fossil fuel based leading to severe negative environmental problems. Besides the negative environmental impacts the energy system is perfectly optimised to satisfy society's needs. This makes that society is 'locked in' the current way of producing and consuming energy. The consequence is that the breakthrough process of renewable energies is slow and tedious.

The aim of this thesis is to contribute to insights necessary to accelerate the diffusion of renewable energy by identifying the underlying factors that induce or block the development, diffusion, and implementation of renewable energies. Biomass energy technologies in the Netherlands and Germany will be used as empirical case studies.

To identify the relevant factors, this thesis starts from the perspective that technological success is not only determined by economic and technical characteristics but also by the *social system* in which a technology – and the knowledge involved – is developed and diffused or rejected. Until now most of the studies are devoted to the techno-economic analysis of renewable energy technologies, however in this thesis the focus will be on the analysis of the social system. To do so, the recently developed 'Innovation Systems' perspective will be applied to analyse the evolution of biomass technologies. More specifically the *Technological Innovation System (TIS)* approach is applied as unit of analysis.

The TIS approach focuses on all actors, networks, organisations and institutions that influence the development, diffusion, rejection or implementation of a particular technology. Recently the TIS approach has developed into a very dynamic approach by not only focusing on the structure of the system (actors, networks and institutions) but also on the key processes that take place within the system and contribute to the build up of a TIS and thereby to the successful development and diffusion of the emerging technology. These key processes are labelled as *Functions of Innovation Systems (or System Functions)* since these are processes that the TIS needs to fulfil in order to perform well. Just like the function of a car is to deliver mobility, the function of a TIS is to generate a number of key processes (System Functions) in order to propel the development of new technology.

Recently a number of studies have applied the System Functions approach, which has led to a number of System Functions lists in the literature. This creates unanimity about which System Functions are relevant. This thesis uses the recently developed list of System Functions at Utrecht University as stated in Table S.1a. This leads to the following research question: *How suitable is the set of System Functions to describe and analyse the dynamics of the TIS?*

Table S.1a Set of Functions of Innovation Systems

Functions of Innovation Systems
F1: Entrepreneurial Activities
F2: Knowledge Development (learning)
F3: Knowledge Diffusion through Networks
F4: Guidance of the Search
F5: Market Formation
F6: Resources Mobilisation
F7: Advocacy Coalition (Creation of legitimacy/Counteract Resistance to Change)

For a technology to develop successfully, the individual System Functions need to be fulfilled. A powerful way of accelerating the individual System Functions is a process of interaction and reinforcement that causes a built-up of virtuous cycles. Literature states that these virtuous cycles are necessary to propel the technology from a fragile state of early development to a robust state of diffusion. Insights in what type of interaction (functional) patterns take place and how exactly these patterns fluctuate over time promise to provide a deeper insight in the dynamics and barriers that hamper technological change. Therefore this thesis aims to answer the next research question: *What do functional patterns tell us about the dynamics of Biomass Innovation Systems?*

The methodology applied is based on the approach by Van de Ven and colleagues in the Minnesota project to study the dynamics of innovation projects. The approach is called *process study* and is based on event analysis. This consists of retrieving events from literature, observations, and interviews that contribute to the change and development of processes, in this case the development, diffusion and implementation of biomass energy technologies. In our case we aim to adapt the methodology that was used to study one innovation *project* to analysing a complete Innovation *System*. This leads to the subsequent research question: *How can the process study approach be applied in order to analyse System Functions and the dynamics of Technological Innovation Systems?*

To recapitulate, by applying the TIS approach the development, diffusion and implementation of a technology is analysed where the System Functions approach is applied to identify the underlying dynamics that hamper or incite the process of technological change. Furthermore the methodology applied is an event based longitudinal process study that allows graphical representation of the individual System Functions and a narrative that provides insights in the development and change process within the TIS studied.

The final aim of this thesis is to make a first step in translating the findings to handholds for policy design that aims to accelerate the diffusion of biomass energy technologies. The fourth and final research question is therefore: *What can we learn from the approach applied and findings obtained, in terms of options to accelerate the diffusion of biomass in particular and renewable energy in general?*

Results and conclusion

The process study was applied in an approach that proved to be a good compromise between completeness and workability with respect to the amount of data collected. The events are mainly collected from archives consisting of newspapers, magazines, and reports etc. from 1980-2004. The events are then ordered into a database and allocated by using a classification scheme to the individual System Functions. From the database, graphical patterns (the sum of events per year per System Function) that represent the individual fulfilment over the years, and a narrative, that illustrates the circumstances that result in the twist and turns of the individual System Functions as well as the interactions between them, are provided. In addition several validation steps (i.e. interviews with experts and intercoder reliability) were taken throughout the data collection and analysis to reduce bias and check on completeness of data. This method is described in detail in Chapter 3 and provides the answer to the research question: *How can the process study approach be applied in order to analyse System Functions and the dynamics of Technological Innovation Systems?*

The System Functions approach helped to structure the vast amount of data and by graphical representations, to highlight crucial breaking points within the narrative. The amount and nature of data collected showed that no System Function was irrelevant (i.e. events were allocated to each System Function) and that no events that could represent an additional System Function were found (i.e. events that could not be allocated to System Function were doubles, external factors or technical or general information categorised as context). Thus, the list of seven System Functions proved to be a good starting point for creating insights in the system dynamics. This provides an answer to research question: *How suitable is the set of System Functions to describe and analyse the dynamics of the TIS?*

The answers to the following research question: *What do functional patterns tell us about the dynamics of Biomass Innovation Systems?* are elaborated for each case study.

The Case of Biomass Digestion in the Netherlands, 1980-2004

For biomass digestion in the Netherlands an irregular functional pattern is observed, as positive and negative System Functions seem to take alternative turns every so many years. In the period 1974-1987 only System Functions such as Knowledge Development (F2) and Entrepreneurial Activities (F1) occur, however no other System Functions are triggered. In the following years, negative guidance against biomass digestion (-F4) hinders any market formation (-F5), investments (-F6) or lobbies to occur (-F7). Only in 1989 a cautious built-up of System Functions occurs when guidance (F4) stimulates knowledge creation and diffusion (F2 and F3) of biomass digestion, resulting in the set up of several plants (F1). However some System Functions remain unfulfilled, such as Market Formation (-F5) and Resource Mobilisation (-F6). These negatively fulfilled System Functions serve as nourishing ground for a vicious cycle to take off in 1995. The trigger is negative guidance (-F4) with respect to biomass digestion, leading to a lack of resources (-F6), forcing several plants to shut down (-F1). This results that only 4 biomass digestion plants are left over in the Netherlands. The only activities that continue are lobby activities (F7), which seem to be heard by the government (F4), when co-digestion is partially permitted several years later. In addition, the government wants to increase the share of green electricity (F4) and introduces a feed-in tariff system (F5). Finally also biomass digestion can profit from this market formation (F5) and an increase of biomass digestion plants (about 18 plants in 2005) occurs in the following years (F1).

This TIS for biomass digestion is evaluated as a poorly functioning system. During long periods no continuous built up of System Functions occurs. Some System Functions are fulfilled but they do not interact with each other as to reinforce each other and trigger other System Functions. This provides a scattered functional pattern that easily collapses if negative System Functions reinforce each other instead.

The Case of Biomass Digestion in Germany 1990-2004
In the case of biomass digestion in Germany, positive interactions between the System Functions lead to the built-up of System Functions. Guidance by the government (F4) triggers entrepreneurs to create and diffuse knowledge (F2, F3), which results in the set up of the first digestion plants (F1). Then lobby activities (F7) start to improve institutional conditions. Shortly after the government increases the feed-in rates (F4). This leads to a market formation (F5), which results in an increase of plants constructed (F1). These activities trigger also other System Functions such as Resource Mobilisation (F6) and Knowledge Diffusion (F3) to be fulfilled, resulting that all System Functions are fulfilled, interact and reinforce each other. Here, a virtuous cycle occurs. This virtuous cycle overcomes a temporary vicious cycles, where negative guidance (-F4) results in a subsidy budget cut (-F6), which then leads to a decrease of projects (-F1). However, this vicious cycle is quickly broken by the provision of financial resources (F6) by another Ministry (F4) and the construction of plants is continued (F1). Then lobby activities (F7) ask for better institutional conditions (F4), and in 2004 better feed-in tariffs are introduced (F5). The feed-in tariffs lead to a market formation, which leads to the final breakthrough of biomass digestion in Germany (i.e. about 1700 plants in 2004) (F1).

This development and diffusion of the technology occurs in a time span of 10 years, where continuous interactions of System Functions reinforce each other as to build-up a virtuous cycle. The built-up is strong enough to overcome a vicious cycle, so that the virtuous cycle continues and a market is formed, which leads to the breakthrough of biomass digestion.

This case shows that technology development is successful when the System Functions are fulfilled, reinforcing each other. However, some critics may say that the case of Germany is a big subsidy story, where the success is attributed to the large amounts of money provided by the government, rather then the System Functions fulfilment. Yet, our analysis clearly shows that the money and the institutional alignment were not in place beforehand, but that due to the build up of System Functions such as Entrepreneurial Activities and Advocacy Coalitions that provided a reliable technology and lobbied for better institutional conditions and financial resources respectively, the alignment occurred gradually over several years. Thus, this shows that the build up of a well functioning Innovation System around a technology plays a crucial role for its successful diffusion, as well as favourable technical and economic aspects.

The Case of Biomass Gasification in the Netherlands, 1980-2004
In the case of biomass gasification first a build up of several System Functions occurs in the period of 1990-1998 due to very high expectations around biomass gasification, such as Guidance of the Search (F4) that trigger Knowledge Creation (F2), Knowledge Diffusion (F3), Resource Mobilisation (F6) and Entrepreneurial activities (F1) to occur. However in 1998 the liberalisation of the energy market triggers a vicious cycle, where negative guidance (-F4) results in the closure of several projects (-F1), less knowledge creation (-F2), less resources (-F6), less research (-F6), negative expectations (-F4) and finally the discontinuation of Entrepreneurial Activities (-F1). These negative events reinforce each other and result that no more activities are carried out

anymore, so that the system collapses within a couple of years. Since then biomass gasification is still not diffused on large-scale.

The main blocking mechanism is the lack of guidance by the government to provide clear and consistent policies (-F4) and the lack of a market niche (-F5), where the actors could have experimented and built-up experience with the technology. At the beginning the expectations are high that biomass gasification will be the solution, however due to unsolved technical problems and inconsistent guidance by the government (-F4), the opinions change drastically as the energy market is liberalised. The liberalisation comes too early for gasification, as it still is an unreliable and expensive technology. Besides the unfortunate timing of the liberalisation, no additional time and space is allowed for trial and error, as to solve the technical problems and investors and government think the technology is unfit and unworthy for further support (-F7), which results in the collapse of the Biomass Gasification Innovation System.

The Case of Biomass Combustion in the Netherlands, 1980-2004

For biomass combustion most of the System Functions are fulfilled and the TIS is built up so far as to be ready to go, however the last crucial trigger is missing to bring about breakthrough. Between 1990-1998 the build-up of a virtuous cycle occurs where guidance (F4) leads to research and knowledge creation (F2), and positive results lead to entrepreneurial activities (F1). However, between 1998-2001 no additional activities occur, nonetheless that biomass combustion is a proven and reliable renewable energy option. This results from the lack of market formation (-F5). As a matter of fact there is a flaw in the tax exemption system that favours the import of green electricity rather than producing it in the Netherlands. However, in 2003, the government introduces a feed-in tariff system (F4) that incites the formation of a market (F5), which directly results in a set up of projects and plants (F1). However in 2005 and 2006 the government decides that new biomass plants are not entitled to feed-in rates, which results that any new and future plans for projects are on hold (-F1). From this case we see, that nonetheless most of the System Functions are fulfilled and that the technology is proven and reliable, as long as there is no secure market formation, the technology will not break through.

The Case of Biomass Co-firing in the Netherlands, 1990-2004

The case of biomass co-firing is somewhat different as it has a head start in comparison to the other biomass case studies. Co-firing means that biomass is added as fuel to existing coal fired power plants. For biomass digestion, gasification and combustion the Innovation System has to be built up from scratch. In the case of biomass co-firing the actors, (coal fired power) plants and infrastructures are already partly in place, being part of the incumbent system. Nonetheless, the dynamics and sequence of events are interesting and provide some lessons for the other case studies. The sequence of events starts with guidance of the government and the energy companies of the incumbent system (F4) to reduce CO_2 emissions, which leads to knowledge development (F2). Co-firing is a very promising option and favourable guidance (F4) and resources (F6) are provided and as a result entrepreneurial activities are set up (F1). Around 2000 there is a temporary vicious cycle, as the institutional conditions are not fully aligned with the needs of the technology and the entrepreneurs (-F4), which leads to a delay in projects (-F1). However due to lobby activities by the energy companies (F7) agreements with the government are finalised (F4), which result that favourable institutional conditions are provided and a market is formed (F5). This is the final trigger to implement co-firing in all coal plants (F1). This case shows that nonetheless the so-called head start, where most of the structural elements were in place, the System Functions need to be fulfilled and that also in this case a Technological Innovation System has to build up around the particular technology before it is successfully diffused and implemented. The crucial factor that leads to the final breakthrough of the technology is also in this case the formation of a market.

The results from the case studies showed that several functional patterns occurred for the Biomass Innovation Systems. These can be divided into virtuous and vicious cycles.

Virtuous cycles occur when several System Functions are fulfilled, interact and reinforce each other and therefore trigger other System Functions to be fulfilled as well. In the case of biomass digestion in Germany and biomass co-firing in the Netherlands, a typical sequence of a virtuous cycle start with the positive fulfilment of Guidance of the Search (F4), with respect to clear and consistent regulations, which triggers entrepreneurial activities (F1) to occur by setting up projects and improving the technology. In addition entrepreneurs lobby (F7) for better regulations and feed-in tariffs. Once these tariffs are introduced (F4), a market is formed (F5) and the number of plants constructed increases rapidly (F1).

On the other hand, when vicious cycles occur either a negative fulfilment of the System Functions occur which results that the System Functions interact and reinforce each other negatively, or that some System Functions are not fulfilled at all and are lacking. In the case of biomass digestion the System Functions are not continuously fulfilled and do not manage to build-up. The main reason is the inconsistent and negative guidance (-F4) that hampers any development or diffusion of biomass digestion technology (-F2, -F1). In addition a lack of resources (-F6) and market formation (-F5) give entrepreneurs a hard time to further develop the technology or to lobby for better conditions. The lack and negative fulfilment of the System Functions results that the diffusion is still small after twenty years, i.e. only about four digestion plants are running in 2004.

For biomass gasification a virtuous cycle turns within a few years into a vicious cycle that makes the biomass gasification innovation system collapse. Due to the liberalisation of the energy market in 1998, most of the System Functions are no longer fulfilled and all activities stop. Mainly the lack of guidance (-F4), resources (-F6) and market formation (-F5) are responsible for the lack in entrepreneurial activities (-F1), so that hardly anymore activities occur after 2000.

Finally for biomass combustion a built-up of System Functions occurs, however the final trigger for breakthrough is missing. As long as no market formation occurs (-F5), only a few small-scale plants are implemented. Once the feed-in tariff system is introduced (F5) an increase of plants and size are observed (F1).

Thus in addition to the necessity of System Functions to interact with each other for a built up to occur, two System Functions is identified that play a crucial role as final trigger for implementation. The influence of Guidance of the Search (F4) is significant in triggering or hampering the further fulfilment of other System Functions. When guidance is negative or lacking, most of the other System Functions are not fulfilled or collapse (see biomass digestion and gasification in the Netherlands), whereas the contrary is true when positive or continuous guidance is provided (biomass co-firing in the Netherlands and biomass digestion in Germany).

Another System Function that is revealed as very critical by the case studies is System Function 5: Market Formation, which shows to be the final trigger that leads to the breakthrough of a technology. Due to the lack of a market, the Biomass Innovation Systems often did not manage to move from a development phase to a breakthrough phase.

Finally, the last question is answered by the following insights.
RQ 4: What can we learn from the approach applied and findings obtained, in terms of options to accelerate the diffusion of biomass in particular and renewable energy in general?

The lessons learned are that biomass technologies go through a long-term trajectory (10-30 years) of development, diffusion and implementation. This asks from a government to develop long-term policy goals and to stick to these policies. In other words, what is needed is a reliable and visionary government. Innovation is a time-consuming search process with many risks. Not taking these dimensions of innovation into account is a guarantee for failure.

From the biomass cases studied it becomes clear that current policy making too often has a too short time horizon. Within long-term policies ample room should be provided for learning and experimenting for technological problems to be resolved, where System Functions need to contribute to this process to occur. This includes providing room for the necessary competences of the actors to develop. Furthermore, this also accounts for policy makers that till now too often (implicitly or explicitly) act from a linear model perspective and should acquire the competences necessary to develop more systemic policies.

Based on the analyses of the systems under development, government should in particular focus on removing barriers hampering virtuous cycles (i.e. inconsistent, contradictory and unstable regulations) and to develop and stimulate the further development of already existing virtuous cycles (i.e. market formation, stable and continuous guidance). Thus, the fulfilment of System Functions such as Guidance of the Search and Market Formation play a crucial role in this context.

In addition entrepreneurs should also take a more active role and realise that they are not innovating in isolation but in the context of a system. They should get involved in processes of guidance, facilitate knowledge exchange and join forces to strengthen their lobby activities. Finally, they should turn into an actor that government cannot ignore any longer.

Samenvatting

De Dynamiek van Technologische Innovatiesystemen – De Casus van Biomassa

Inleiding

Het uitgangspunt van dit proefschrift is het probleem dat ons huidige energievoorzieningsysteem voornamelijk op fossiele energie gebaseerd is, wat leidt tot ernstige milieuproblemen en afhankelijkheid van politiek instabiele regio's. Afgezien van deze negatieve effecten is het huidige energiesysteem geoptimaliseerd ten aanzien van de behoeften van de maatschappij; goedkoop, betrouwbaar, en relatief veilig. Hierdoor is de huidige manier van het produceren en consumeren van energie moeilijk te veranderen op korte termijn; we spreken dan ook van "lock-in". Als gevolg hiervan hebben duurzame energiebronnen moeite om grootschalig door te breken binnen het huidige energiesysteem.

Het doel van dit proefschrift is om bij te dragen aan de benodigde inzichten om de diffusie van duurzame energie te versnellen, door de relevante factoren te identificeren die de ontwikkeling, diffusie en implementatie van duurzame alternatieven in gang zetten, versnellen dan wel blokkeren. De ontwikkeling van biomassa-energietechnologieën in Nederland en Duitsland worden hierbij gebruikt als empirische case studies.

Om de relevante factoren te identificeren, gaat dit proefschrift uit van het perspectief dat technologisch succes niet alleen wordt bepaald door economische en technische eigenschappen. Ook het *sociale systeem* waarin een technologie – en de benodigde kennis – wordt ontwikkeld bepaalt het succes van een technologie. Tot op heden zijn de meeste studies gericht op de techno-economische analyse van duurzame energietechnologieën; in dit proefschrift zal de analyse zich juist richten op het sociale systeem. Hiervoor wordt het recentelijk ontwikkelde 'Innovatiesysteem' perspectief toegepast om de evolutie van biomassatechnologieën te analyseren: het Technologisch Innovatiesysteem (TIS) is eenheid van analyse.

De TIS benadering focusseert op alle actoren, netwerken, organisaties en instituties die de ontwikkeling, diffusie, implementatie of verwerping van een bepaalde technologie beïnvloeden. Onlangs is de TIS benadering ontwikkeld tot een zeer dynamische aanpak. Niet langer wordt alleen de structuur van het systeem (actoren, netwerken en instituties) in ogenschouw genomen, maar ook de sleutelprocessen die plaatsvinden binnen het systeem. Deze sleutelprocessen dragen bij aan de opbouw van een TIS en daarmee ook aan de succesvolle ontwikkeling en diffusie van een opkomende technologie. Deze sleutelprocessen worden *Functies van Innovatiesystemen* (of *Systeem-Functies*) genoemd, omdat het processen betreft die het TIS moet vervullen om tot goede prestaties te komen. Zoals het de functie van een auto is om mobiliteit te leveren, zo is het de functie van een TIS om een aantal sleutelprocessen (Systeem-Functies) te genereren en zodoende de ontwikkeling van een nieuwe technologie voort te stuwen. Een aantal studies heeft getracht Systeem-Functies te identificeren, wat heeft geleid tot een zekere discussie over welke

Tabel S.1b De set van Systeem-Functies

Systeem-Functies
F1 Experimenteren door entrepreneurs
F2 Kennisontwikkeling
F3 Kennisdiffusie in netwerken
F4 Richting geven aan het zoekproces
F5 Creëren van markten
F6 Mobiliseren van middelen
F7 Creëren van legitimiteit/creatieve destructie

Systeem-Functies het meest relevant zijn. In dit proefschrift wordt gebruik gemaakt van de verzameling Systeem-Functies die ontwikkeld is aan de Universiteit Utrecht (zie tabel S.1b). Dit leidt tot de volgende onderzoeksvraag: *Hoe geschikt is deze verzameling van Systeem-Functies om de dynamiek van het TIS te beschrijven en analyseren?*

De veronderstelling is dat als de individuele Systeem-Functies worden vervuld, de technologie de meeste kans heeft om succesvol ontwikkeld te worden. Een krachtige manier om de vervulling van individuele Systeem-Functies te versnellen is een proces van interactie en versterking dat leidt tot het ontstaan van positieve terugkoppelingen. In de literatuur wordt gesteld dat deze positieve terugkoppelingen noodzakelijk zijn om technologie van de fragiele situatie van prille ontwikkeling, naar een robuuste staat van diffusie te brengen. Inzichten in welke type (functionele) interactiepatronen plaatsvinden, en hoe deze patronen fluctueren over tijd, beloven een dieper inzicht in de dynamiek van technologische verandering en in de barrières die deze verandering in de weg staan. Daarom heeft dit proefschrift als volgende onderzoeksvraag: *wat voor inzicht geven de functionele patronen in de dynamiek van biomassa innovatiesystemen?*

De gebruikte methodologie is gebaseerd op de benadering Van de Ven en collegae, die door hen ontwikkeld is om de dynamiek van innovatieprojecten te bestuderen. Deze zogenoemde 'process study' is gebaseerd op de analyse van zogenaamde 'events' (i.e. gebeurtenissen). Deze bestaat uit het achterhalen van relevante gebeurtenissen uit literatuur, observaties en interviews, die hebben bijgedragen aan verandering en ontwikkeling van processen, in dit geval de ontwikkeling, diffusie en implementatie van biomassa energietechnologieën. Een neven doel van dit proefschrift is om de methodologie die gebruikt is om innovatieprocessen op projectniveau te analyseren, aan te passen zodat het geschikt is voor de analyse van innovatieprocesen op *Innovatiesysteemniveau*. Dit is de aanleiding voor volgende onderzoeksvraag: *Hoe kan de 'process study' benadering toegepast worden om de Systeem-Functies en de dynamiek van Technologisch Innovatiesysteem te analyseren?*

Door de analyse van Systeem-Functies kunnen we de dynamiek van het TIS in kaart brengen en succes- en faalfactoren bepalen die de ontwikkeling, diffusie en implementatie van een technologie beïnvloeden. Het uiteindelijk doel van het proefschrift is om op basis hiervan handvatten voor beleidsmakers te formuleren waarmee de diffusie van biomassa energie technologieën versneld kan worden. Dus de vierde een laatste vraag is: *Wat kunnen we leren van de toegepaste aanpak en de resultaten, in termen van beleidsopties om in het bijzonder de diffusie van biomassa en in het algemeen duurzame energietechnologieën te versnellen?*

Resultaten en conclusies

The 'process study' methode heeft bewezen een goed compromis te zijn tussen enerzijds compleetheid van data en werkbaarheid anderzijds. De geanalyseerde gebeurtenissen komen met name uit krantenarchieven en grijze literatuur. De gebeurtenissen zijn geordend in een database en toegedeeld aan de Systeem-Functies middels een allocatieschema. Middels de database is het mogelijk gebleken om grafische patronen te laten zien die de vervulling van de individuele Systeem-Functies representeren. Deze grafische patronen ondersteunen vervolgens het verhaal dat de samenhang tussen de gebeurtenissen beschrijft. Verschillende validatiestappen (interviews met experts, beoordeling verhaallijn door experts) zijn ingebouwd om eenzijdige interpretatie door de onderzoeker te voorkomen. De hierboven samengevatte methode is uitgebreid beschreven in hoofdstuk 3 en beantwoord daarmee onderzoeksvraag *Hoe kan de 'process study' benadering toegepast worden om de Systeem-Functies en de dynamiek van Technologisch Innovatiesysteem te analyseren?*

De verzameling van Systeem-Functies heeft geholpen in het ordenen van de grote aantallen gebeurtenissen die zijn opgeslagen in de databases. Ook de grafische weergaven heeft geholpen om kritieke momenten in de tijdslijn op te sporen. Het toekennen van gebeurtenissen aan de Systeem-Functies heeft ertoe geleid dat we kunnen stellen dat de verzameling van zeven Systeem-Functies een uitstekend startpunt is voor de analyse van innovatiesysteemdynamiek. Er zijn namelijk geen duidelijke gebeurtenissen overgebleven die niet aan de zeven Systeem-Functies konden worden toegekend en tevens bleek dat elke Systeem-Functie een aanzienlijk aantal gebeurtenissen te bevatten. De verzameling lijkt dus volledig te zijn en geen overbodige Systeem-Functies te bevatten. Dit vormt daarmee het antwoord op de vraag: *Hoe geschikt is deze verzameling van Systeem-Functies om de dynamiek van het TIS te beschrijven en analyseren?*

Het antwoord op vraag: *'Wat voor inzicht geven de functionele patronen in de dynamiek van biomassa innovatiesystemen?'* wordt besproken per onderzochte casus.

De casus biomassavergisting in Nederland, 1980-2004
Voor biomassavergisting in Nederland wordt een onregelmatig functioneel patroon waargenomen, aangezien positieve en negatieve Systeem-Functies elkaar om de paar jaar afwisselen. In de periode 1974-1987 vonden alleen de Systeem-Functies kennisontwikkeling (F2) en experimenteren door entrepreneurs (F1) plaats, terwijl geen van de andere Systeem-Functies werden geobserveerd in deze periode. In de daaropvolgende jaren hinderde het feit dat er negatief richting werd geven aan biomassavergisting (-F4), het creëren van een markt afwezig was (-F5), nauwelijks investeringen plaatsvonden (-F6) en het creëren van legitimiteit achterwege bleef (-F7). Alleen in 1989 vond een voorzichtige opbouw van Systeem-Functies plaats doordat richting geven aan het zoekproces (F4) begon plaats te vinden, wat kennisontwikkeling en kennisdiffusie met betrekking tot biomassavergisting op gang deed komen (F1, F2). Dit resulteerde in de bouw van verscheidene installaties (F1). Desondanks, werden enkele Systeem-Functies niet vervuld, zoals het creëren van markten (-F5) en het mobiliseren van middelen (-F6). Deze negatief vervulde Systeem-Functies bleken een voedingsbodem voor een proces van negatieve terugkoppeling, die in 1995 begon. De aanleiding was het negatief richting geven (-F4) aan biomassavergisting, wat leidde tot een tekort aan middelen (-F6) wat vervolgens

verschillende installaties tot sluiting dwong (-F1). Als gevolg daarvan bleven nog maar vier biomassavergistingsinstallaties in Nederland over.

De enige activiteiten die toen doorgang vonden, waren gericht op het creëren van legitimiteit (F7) en lijken door de overheid gehoord te zijn (F4), aangezien co-vergisting enkele jaren later gedeeltelijk werd toegestaan. Dit is een belangrijke methode om meer methaangas uit vergistinginstallaties te winnen wat de rentabiliteit verhoogt. Een volgende stimulans voor vergisting diende zich aan met de ambitie van de overheid om het aandeel groene stroom (F4) te vergroten en een systeem van terugleververgoedingen introduceerde (F5). Uiteindelijk kon ook biomassavergisting profiteren van deze marktcreatie (F5) en in de daaropvolgende jaren vond een stijging van het aantal biomassavergistingsinstallaties plaats (rond de 18 installaties in 2005) (F1).

Het Technologisch Innovatiesysteem voor biomassavergisting in Nederland kan worden geëvalueerd als een slecht functionerend systeem. Gedurende lange perioden vindt er namelijk geen continue opbouw van Systeem-Functies plaats. Hoewel sommige Systeem-Functies worden vervuld, werken deze echter niet op elkaar in, om op die manier elkaar te versterken en andere Systeem-Functies te stimuleren. Dit zorgt voor een instabiel functioneel patroon dat gemakkelijk in elkaar stort als negatieve Systeem-Functies elkaar wel versterken.

De casus biomassavergisting in Duitsland, 1990-2004

In de casus biomassavergisting in Duitsland leiden positieve terugkoppelingen tussen Systeem-Functies tot de opbouw van Systeem-Functies. Het richting geven aan het zoekproces door de overheid (F4) stimuleerde de entrepreneurs om kennis te creëren en te diffunderen (F2, F3), wat resulteerde in het bouwen van de eerste vergistinginstallaties (F1). Vervolgens begonnen de institutionele condities te verbeteren als gevolg van ondernemersactiviteiten die betrekking hadden op het creëren van legitimiteit (F7). Kort daarna verhoogde de overheid de terugleververgoedingen (F4). Dit creëerde direct een markt (F5), wat vervolgens resulteerde in een stijging van het aantal gebouwde installaties (F1). Deze activiteiten zorgden er ook voor dat andere Systeem-Functies, zoals het mobiliseren van middelen (F6) en kennisdiffusie (F3) werden vervuld. We observeren een patroon dat alle Systeem-Functies worden vervuld, op elkaar inwerken en elkaar versterken. Hier vindt duidelijk een positieve terugkoppeling plaats. Deze positieve terugkoppeling overwint een tijdelijke negatieve terugkoppeling waar negatief richting geven (-F4) resulteerde in een vermindering van het subsidiebudget (-F6), wat vervolgens leidde tot een vermindering van het aantal projecten (-F1). Maar deze negatieve spiraal is snel doorbroken doordat er door een ander ministerie (F4) werd voorzien in financiële middelen (F6) en de bouw van de installaties werd gecontinueerd (F1). Vervolgens vonden er lobby activiteiten (F7) plaats die vroegen om betere institutionele condities (F4). In 2004 werden er betere terugleververgoedingen geïntroduceerd. Deze terugleververgoedingen leidden tot het creëren van een markt (F5), welke resulteerde in de uiteindelijke doorbraak van biomassa vergisting in Duitsland (ongeveer 1700 installaties in 2004) (F1).

Deze casus laat zien dat technologieontwikkeling succesvol is als de Systeem-Functies vervuld zijn en elkaar versterken. Maar sommige critici zullen zeggen dat de casus van Duitsland één groot subsidieverhaal is, waar het succes voor een groot gedeelte te danken is aan het geld dat door de overheid beschikbaar werd gesteld en niet zozeer aan het vervullen van de Systeem-Functies. Toch laat onze analyse duidelijk zien dat goede afstemming tussen de behoeften van de technologie en de institutionele condities niet van tevoren aanwezig was, maar dat deze afstemming geleidelijk over verschillende jaren tot stand kwam als *gevolg* van een opbouw van verschillende Systeem-Functies, zoals experimenten van entrepreneurs, kennisontwikkeling, goede lobby activiteiten en duidelijk richting geven aan het zoekproces. Deze casus laat dus zien dat de opbouw van een goed functionerend Innovatiesysteem rondom een technologie een cruciale rol speelt in een succesvolle diffusie van de technologie. Deze casus heeft ook laten zien dat goed functionerende technologie sterk heeft bijgedragen aan de opbouw van een dergelijk goed functionerend innovatiesysteem.

De casus biomassavergassing in Nederland, 1980-2004
In de casus van biomassavergassing laat zien dat de hoge verwachtingen in de periode 1990 – 1998 rondom biomassavergassing sterk richting gevend hebben gewerkt (F4). Dit beïnvloedde een proces van kenniscreatie (F2), kennisdiffusie (F3), mobilisatie van middelen (F6) en experimenten door entrepreneurs (F1). In 1998 bracht de liberalisering van de energiemarkt echter vrij abrupt een negatieve spiraal op gang, waarin negatieve sturing (-F4) leidde tot het sluiten van een aantal projecten (-F1), minder kenniscreatie (-F2), minder middelen (-F6), minder onderzoek (-F6), negatieve verwachtingen (-F4) en tot slot de beëindiging van activiteiten van entrepreneurs (-F1). Deze negatieve gebeurtenissen versterkten elkaar en leidden ertoe dat er geen activiteiten meer werden uitgevoerd, zodat het systeem binnen een paar jaar instortte. Sindsdien is biomassavergassing bezig weer op te krabbelen maar tot diffusie heeft dit nog steeds niet geleid.

De liberalisering kwam dus te vroeg voor vergassing, want dat was op dat moment nog steeds een onbetrouwbare en dure technologie. Het nieuwe referentiekader deed de meningen van actoren over vergassing snel en drastisch veranderen. Voor de liberalisering was vergassing een beloftevolle technologie dat nog wat tijd nodig had om tot bloei te komen, ten tijde van de liberalisering was vergassing een dure, onbetrouwbare technologie dat niet geschikt was om in een geliberaliseerde markt te concurreren met andere opties.

Wat de vergassingstechnologie dus op dat moment nodig had was een sterke overheid die deze beloftevolle technologie kon beschermen tegen de sterk opkomende marktkrachten. Dit is niet gebeurt. Er was onvoldoende sturing door de overheid om helder en consistent beleid te ontwikkelen ten aanzien van deze veel belovende maar nog niet uitontwikkelde technologie (-F4) en tevens een gebrek aan een marktniche (-F5) waar de actoren hadden kunnen experimenteren en ervaring hadden kunnen opdoen met vergassingstechnologie. Het resultaat was het instorten van het Biomassavergassings Innovatiesysteem.

De casus biomassaverbranding in Nederland, 1980-2004
Voor biomassaverbranding zijn de meeste Systeem-Functies vervuld en het TIS is ver genoeg opgebouwd om snelle groei mogelijk te maken. Alleen de laatste cruciale trigger die nodig is om een doorbraak teweeg te brengen ontbreekt. Tussen 1990 en 1998 vond positieve terugkoppeling plaats tussen de Systeem-Functies sturing (F4), onderzoek en kenniscreatie (F2) en ondernemersactiviteiten (F1). Tussen 1998 en 2001 vonden echter geen verdere activiteiten plaats, ondanks het feit dat biomassaverbranding een bewezen en betrouwbare optie voor hernieuwbare energie was. De oorzaak lag in het gebrek aan marktcreatie (-F5). Door een fout in het stimuleringssysteem voor duurzame energie was de import van groene stroom voordeliger dan productie in Nederland. Dit leidde tot veel import van duurzame energie en weinig nieuwe projecten in Nederland. In 2003 herstelde de overheid dit manco en introduceerde een systeem van terugleververgoedingen (F4) dat een markt (F5) creëerde voor duurzame energie. Dit resulteerde snel in nieuwe projecten en installaties (F1). In 2005 en 2006 besloot de overheid

echter dat nieuwe biomassa-installaties niet in aanmerking kwamen voor terugleververgoedingen, met als gevolg dat alle nieuwe en toekomstige plannen voor projecten in de wacht kwamen te staan (-F1). Deze casus leert ons dat hoewel de meeste Systeem-Functies vervuld zijn en de technologie bewezen en betrouwbaar is, de creatie van een markt een essentiële voorwaarde is voor succesvolle technologie diffusie.

De casus bijstoken van biomassa in Nederland, 1990-2004
De casus over bijstoken van biomassa verschilt enigszins van de andere, omdat deze vorm van elektriciteitsproductie gebaseerd op biomassa een voorsprong had. Bijstoken betekent dat biomassa wordt toegevoegd als brandstof aan bestaande kolengestookte elektriciteitscentrales. Voor de vergisting, vergassing en verbranding van biomassa, moest het innovatiesysteem vanuit het niets worden opgebouwd. Bij bijstoken van biomassa waren de actoren, de centrales en de infrastructuur al aanwezig als onderdeel van het bestaande energiesysteem. Desalniettemin zijn de dynamiek en de volgorde/sequentie van de gebeurtenissen interessant en verschaffen ze lessen voor de andere casussen. De reeks met gebeurtenissen begon met de sturing van de overheid richting energiemaatschappijen (F4) om de CO_2-emissie te reduceren, wat leidde tot kennisontwikkeling (F2). Bijstoken werd gezien als een veelbelovende optie (F4) en middelen (F6) werden verschaft. Dit resulteerde in verschillende ondernemingsactiviteiten (F1). Rond 2000 ontstond een tijdelijke negatieve spiraal, omdat de institutionele voorwaarden niet geheel overeenkwamen met de behoeften van de technologie en de ondernemers (-F4). Dit leidde tot een vertraging in de projecten (-F1). Door lobbyactiviteiten van energiemaatschappijen (F7) werd overheidsbeleid wat aangepast (F4), wat resulteerde in gunstige institutionele condities en een markt voor bijstook (F5). Dit bleek een beslissende stimulans om bijstoken te implementeren in kolencentrales (F1). Deze casus laat zien dat, ondanks de initiële voorsprong waar de meeste structurele elementen aanwezig waren, de Systeem-Functies nog steeds moeten worden vervuld en dat ook hier het technologische innovatiesysteem moet worden opgebouwd rond een bepaalde technologie voordat het succesvol kan diffunderen. De cruciale factor die leidde tot de uiteindelijke doorbraak van de technologie was ook in deze casus de creatie van een markt.

Dus, het geanalyseerde empirische materiaal heeft laten zien dat de vervulling van de zeven Systeem-Functies noodzakelijk is voor succesvolle technologieontwikkeling. We hebben ook laten zien dat positieve terugkoppelingen tussen Systeem-Functies belangrijk zijn om functievervulling te versnellen. Verder is opgevallen dat een tweetal Systeem-Functies een cruciale rol hebben gespeeld in de ontwikkeling van biomassa energie in Nederland. De invloed van de Systeem-Functie 4 “richting geven aan het zoekproces” is telkens weer een kritieke factor gebleken in het initiëren dan wel tegenwerken van de verdere vervulling van andere Systeem-Functies. Het negatief vervuld zijn dan wel het afwezig zijn van deze Systeem-Functies leidde een aantal maal tot het ineenstorten van het Innovatiesysteem (zie biomassa vergisting en vergassing in Nederland). Het tegengestelde hebben we ook geobserveerd. Indien er voorzien is in positieve of continue sturing (zie biomassa bijstoken in Nederland en biomassa vergisting in Duitsland) had dit een zeer positieve uitwerking op andere Systeem-Functies. En andere Systeem-Functies die we als kritisch kunnen bestempelen is Systeem-Functie 5 “marktcreatie”. Deze Systeem-Functie blijkt cruciaal te zijn om een laatste zet te geven aan de doorbraak van technologie. Door het afwezig blijven van een markt kon het Biomassa Innovatiesysteem het vaak niet voor elkaar krijgen om van de ontwikkelingsfase over te gaan naar de diffusiefase.

Tot slot beantwoorden we de laatste vraag: *Wat kunnen we leren van de toegepaste aanpak en de resultaten, in termen van beleidsopties om in het bijzonder de diffusie van biomassa en in het algemeen duurzame energietechnologieën, te versnellen?*

De lessen die we geleerd hebben zijn dat biomassa technologieën een lang traject van ontwikkeling, diffusie en implementatie nodig hebben. Dit vraagt van de overheid om lange termijn beleidsdoelen te ontwikkelen en deze consequent uit te voeren. In andere woorden, wat duurzame energietechnologie nodig heeft is een betrouwbare en visionaire overheid. Innovatie is een zoekproces dat veel tijd kost en veel risico's met zich meedraagt. Het niet rekening houden met deze eigenschappen is een recept voor falen.

Uit het empirische materiaal over biomassa wordt het duidelijk dat het huidige beleid zich maar al te vaak richt op de korte termijn. Hierdoor worden ondernemers en onderzoekers geconfronteerd met snel elkaar afwisselende signalen en regelingen. Dit is funest voor het ontstaan van een positief interactie patroon tussen verschillende Systeem-Functies. Dit proefschrift heeft nu juist aangetoond dat dit soort interactiepatronen noodzakelijk zijn. Dus zou beleid een lange termijn visie dienen te hebben, veel ruimte bieden aan leren en experimenteren om zodoende technologische problemen het hoofd te kunnen bieden en aandacht moeten hebben voor de vervulling van Systeem-Functies. Indien bepaalde Systeem-Functies niet of nauwelijks worden vervuld dan zou dit een signaal moeten zijn voor additioneel beleid. Op deze manier kan een optimale afstemming ontstaan tussen de behoeften van een zich ontwikkelend innovatie systeem en de stimulering en bescherming die wordt geboden door de institutionele kaders. Dit vraagt dus om een systeemperspectief ten aanzien van technologieontwikkeling bij beleidsmakers in plaats van het lineaire innovatie model dat nu nog vaak de boventoon voert.

Het is echter niet alleen de overheid die bepalend is voor het succes of falen van nieuw technologie. Ook ondernemers spelen een cruciale rol. Het empirische materiaal heeft aangetoond dat goed georganiseerde ondernemers met een krachtige lobby richting de overheid succesvoller zijn dan slecht georganiseerde ondernemers. Ondernemers hebben dus niet alleen de taak om zich te richten op de primaire processen van ondernemerschap, maar dienen ook verantwoordelijkheid te nemen voor het richting geven aan het zoekproces, het faciliteren van kennisdiffusie en het samenwerken in lobbyactiviteiten.

Zusammenfassung

Die Dynamik technologischer Innovationssystemen – Fallbeispiel Bio-energie

Die heutige Energieversorgung basiert zu einem wesentlichen Teil auf fossilen Brennstoffen. Die Dominanz fossiler Energieträger, welche von Unruh (2000) als „carbon lock-in“ bezeichnet wird, führt dazu, dass die Nutzung und Verbreitung erneuerbarer Energiequellen nur langsam voranschreitet und oft mit großen Hemmnissen verbunden ist. Die Leitfrage der vorliegenden Arbeit lautet daher:

Wie kann der carbon lock-in der heutigen Energieversorgung durchbrochen werden, um die Diffusion von neuen Technologien im Bereich der erneuerbaren Energien zu beschleunigen?

Um diese Frage zu beantworten wird die Entwicklung und Diffusion von erneuerbaren Energien systematisch analysiert. Ein für diese Analyse sehr gut geeignetes Konzept ist das *Technologische Innovationssystem (TIS)* (Carlsson and Stankiewicz 1991). Dabei werden Innovations- und Diffusionsprozesse aus der Sicht einer spezifischen Technologie betrachtet und alle Faktoren (Akteure, Institutionen und Netwerke), die die Entwicklung der Technologie beeinflussen, berücksichtigt.

Die neuere Forschung hat verschiedene, so genannte *System-Funktionen,* identifiziert, die erfüllt sein müssen, damit ein TIS die Entwicklung einer neuen Technologie erfolgreich unterstützt. Die Funktionen, die in dieser Arbeit betrachtet werden, lauten: F1: unternehmerische (Innovations-)Aktivitäten, F2: neues Wissen hervorbringen, F3: Wissen durch Netwerke verbreiten, F4: die Richtung der Forschung lenken, F5: Märkte bilden, F6: Ressourcen für den Innovationsprozess bereitstellen, F7: Widerstände gegenüber Veränderungen abbauen.

Wenn die Analyse diese verschiedenen Funktionen berücksichtigt, werden alle Schlüsselprozesse, die im TIS vorkommen und die einen Einfluss auf die Entwicklung, Diffusion und Anwendung der untersuchten Technologie haben, identifiziert und der Einblick in die Systemdynamik wird gewährleistet. Die System-Funktionen sind nicht unabhängig voneinander, sondern beeinflussen sich gegenseitig. Je nach Art und Weise der Interaktion wird die Gesamtleistung des technologischen Innovationssystems positiv oder negativ beeinflusst. Wenn System-Funktionen positiv aufeinander wirken führt das zu einer positiven Rückkopplung und einem starken Moment, welches dazu führen kann, dass etablierte Strukturen wie etwa der 'carbon lock-in' aufgebrochen werden. Ebenso können negative Interaktionen negative Rückkopplungseffekte in Gang setzen und ein TIS erheblich schwächen oder sogar zu dessen Niedergang führen.

Um die Dynamik von technologischen Innovationssystemen und insbesondere derartige Rückkopplungszyklen und Entwicklungspfade zu untersuchen wird die Methode der historischen Event Analyse verwendet (Van de Ven 1990; Poole et al. 2000). Damit wird die zeitliche Entwicklung von vier TIS im Bereich der Energieerzeugung aus Biomasse rekonstruiert. Die vier untersuchten Fallstudien beinhalten die Entwicklung, Diffusion und Anwendung von Biomasse Vergärung, Vergasung und Verbrennung in den Niederlanden von

1980 bis 2004 und Biomasse Vergärung in Deutschland von 1990 bis 2004. Als empirische Grundlage werden Daten aus der wissenschaftlichen Literatur, aus Fachzeitschriften, Archiven und anderen Dokumenten herangezogen. Die Faktoren, die wesentliche Veränderungen und Richtungsänderungen innerhalb des jeweiligen Innovationssystems hervorgerufen haben, werden zum einen quantitativ erfasst und zum anderen qualitativ in Form einer Erzählung aufbereitet.

Aus den vier Biomasse Fallstudien wurden folgende Erkenntnisse gewonnen. Im Fall der Biomasse-Vergärung in Deutschland und der Biomasse-Mitverbrennung in den Niederlanden, sind positive Rückkopplungseffekte eingetreten, während bei der Vergärung, der Vergasung und auch bei der Verbrennung in den Niederlanden vor allem negative Prozesse zu beobachten waren.

In den ersten beiden Innovationssystemen haben sich die System-Funktionen gegenseitig verstärkt. Die Hauptgründe für die erfolgreiche Diffusion der Biomasse-Vergärung und der Mitverbrennung in konventionellen Kraftwerken waren vor allem förderliche Vorschriften (etwa im Bereich der Genehmigung, F4), effektive Vergütungssysteme für erneuerbare Energien (F5), und zahlreiche unternehmerische Aktivitäten (F1). Dabei war zu beobachten, dass die Unternehmen gemeinsam für günstigere Vorschriften lobbyiert und gleichzeitig die Technologie weiterentwickelt und neue Projekte gestartet haben.

In den anderen untersuchten Innovationsfallstudien war eine negative Interaktion zwischen den System-Funktionen verantwortlich für die Entstehung negativer Effekte. Dies hat nicht nur den Aufbau der Innovationssysteme verhindert, sondern einen möglichen Niedergang begünstigt. Im Fall der Biomasse-Vergasung in den Niederlanden war ein Mangel bei der Lenkung der Forschungsaktivitäten (F4) zu beobachten: die Regierung und die Energieversorgungsunternehmen haben die neue Technologie nicht weiter unterstützt, weil zum Zeitpunkt der Energiemarktliberalisierung die technischen Probleme noch immer nicht gelöst waren. Letztlich hatte man damit die Technologie nicht einmal 10 Jahre lang erprobt. Bei der Biomasse-Vergärung in den Niederlande waren ungünstige und inkonsistente Vorschriften (F4) sowie ein Mangel an Marktformation (F5) verantwortlich dafür, dass im Vergleich zu Deutschland nur wenige Anlagen errichtet wurden. Im Fall der Biomasse-Verbrennung waren schließlich die meisten System-Funktionen erfüllt und auch positive Interaktionen sichtbar. Dennoch ist kein echter Durchbruch entstanden. Dies kann man dem Umstand zuschreiben, dass die Bildung eines Marktes nicht vorangekommen ist (F5): Obwohl die Technologie zuverlässig war, wurden nicht mehr als vier Kleinanlagen gebaut während 20 Jahren. Mit der Einführung einer höheren Vergütung (Einspeisungsgesetz) hat sich die Situation nun verändert. So waren zuletzt deutlich mehr unternehmerische Aktivitäten zu beobachten und es wird auch an Großanlagen gedacht.

Mit Blick auf die eingangs formulierte Fragestellung können folgende Schlüsse gezogen werden. Technologien im Bereich der Energieerzeugung aus Biomasse benötigen viele Jahre, zum Teil sogar bis zu drei Jahrzenten für die technologische Entwicklung, Diffusion und Anwendung. Die holländische Regierung hat jedoch immer nur kurzfristige Förder-Richtlinien erstellt und jegliche Unterstützung eingestellt, sobald die technischen Probleme nicht innerhalb kurzer Frist gelöst wurden. Im Gegensatz dazu wäre eine langfristige und stabile Förderung und Lenkung der Forschung seitens der Regierung erforderlich gewesen. Es hätte Zeit und Raum bedurft zum

Experimentiern und Ausprobieren, so dass ein Markt entstehen kann und Unternehmer eine Lobby bilden, die sich wiederum für bessere institutionelle Rahmbedingungen einsetzt.

Mit Blick auf den konzeptionellen Ansatz und die Erhebungsmethodik hat sich die historische Event Analyse als geeignet erwiesen, weil eine große Menge von Daten integriert werden konnte und der Auswertungsaufwand gleichzeitig noch kontrollierbar war. Um mögliche Verzerrungen bei der Interpretation zu vermeiden wurden ergänzend zur Event Analyse auch Interviews mit Experten durchgeführt.

Das Konzept der System-Funktionen hat sich ebenfalls als hilfreich erwiesen, um die grosse Menge von Daten zu strukturieren. Es bietet zugleich einen guten Ausgangspunkt, um Einblick in die Systemdynamik zu bekommen. Alle gefundenen Ereignisse (events) konnten einer oder mehrer Funktionen zugeordnet werden. Das bedeutet, dass das Set von System-Funktionen im vorliegenden Fall ausreichend war für die Analyse. Gleichzeitig wurden auch sämtliche Funktionen benötigt, d.h. keine System-Funktion war überflüssig.

Insgesamt bietet die für alle vier Fallstudien angewendete Methodik der Analyse einen guten Rahmen, um die mühvolle Entwicklung, Diffusion und Anwendung von neuen Technologien mit der von erfolgreichen Technologien zu vergleichen. Man erhält einen systematischen Einblick in die Interaktion der unterschiedlichen System-Funktionen, welche dann die technologische Entwicklung hemmen oder ansporen. Auf dieser Basis können letztlich Förderrichtlinien und Anreizstrukturen entwickelt werden, um die Entwicklung, Diffusion und Anwendung von neuen Technologien, wie etwa die Energieerzeugung aus Biomasse, zu beschleunigen.

Riassunto

Sulla dinamica dei Sistemi di Innovazione Tecnologica – Il caso dell'energie da biomasse

Il punto di partenza di questa tesi di dottorato e' la dipendenza dell'attuale sistema energetico dai combustibili fossili. Questa situazione, denominata da Unruh (2000) 'carbon lock-in', ovvero blocco da carbonio, rende la diffusione di energie rinnovabili lunga, lenta e difficoltosa. E' quindi importante chiedersi: *'Come superare l'attuale situazione di lock-in da carbonio ed accelerare la diffusione di tecnologie di energia rinnovabile nella societa'?*

Per rispondere a questa domanda, si rende necessario aprire la scatola nera del lock-in da carbonio e analizzare in maniera dettagliata come avvengano lo sviluppo e la diffusione di energie rinnovabili.

L'approccio teorico piu' adatto ad analizzare lo sviluppo, la diffusione e l' implementazione di tecnologie emergenti e' la prospettiva dei Sistemi di Innovazione Tecnologica (SIT), sviluppata da Carlsson e Stanckiewicz (1991). Questo approccio si concentra su una specifica tecnologia e include tutti quei fattori (istituzioni, attori e networks) che influenzano il suo sviluppo.

Recenti risultati di ricerca hanno identificato diverse cosiddette *Funzioni di Sistema* che devono essere eseguite affinche' un SIT possa supportare con successo l'evoluzione di una tecnologia. In questo lavoro faremo uso del seguente insieme di Funzioni di Sistema: F1: Attivita' Imprenditoriali, F2: Sviluppo di Conoscenze (apprendimento), F3: Diffusione di Conoscenze attraverso Networks, F4: Orientamento della Ricerca, F5: Formazione del Mercato, F6: Mobilitazione delle Risorse, F7: Reazione alla Resistenza al Cambiamento (o Supporto da parte di Gruppi di Pressione).

Concentrandosi sulle Funzioni di Sistema, verranno identificati quei processi chiave che caratterizzano il sistema che influenza lo sviluppo, la diffusione e l'implementazione della tecnologia in questione, (e verra' chiarita la dinamica di tale sistema). Le Funzioni di Sistema non sono indipendenti, ma interagiscono e si influenzano a vicenda. La natura di tali interazioni, positive o negative, influenza la prestazione del sistema. La riuscita positiva delle Funzioni di Sistema puo' portare a cicli di processi positivi, ovvero virtuosi, che si rafforzano a vicenda e che portano al formarsi di un 'momento' che crea un processo di 'distruzione creativa' all' interno del sistema esistente (Jacobsson e Bergek 2004). Seguendo lo stesso ragionamento, un sistema in declino e' caratterizzato da uno o piu' *circoli viziosi*, nei quali le Funzioni di Sistema interagiscono e si rinforzano a vicenda in modo negativo.

Al fine di identificare e analizzare tali cicli, adatteremo e applicheremo a livello del Sistema di Innovazione, l'approccio di studio per processi (Van de Ven 1990; Poole et al. 2000), con l'intento di studiare la dinamica dei processi di innovazione, e ricostruiremo le traiettorie tecnologiche di quattro tecnologie di energia da biomassa. Tale metodo di ricerca longitudinale si è dimostrato efficace nell' analisi delle dinamiche di innovazione (Van de Ven 1990; Van de Ven et al. 1999). Nel nostro caso viene ricostruita una tempistica basata sugli eventi rintracciati in letteratura e tale tempistica viene illustrata con una narrativa nella quale sono identificate le circostanze che producono determinati cambi di direzione.

I risultati dei casi studio dimostrano che nel caso dei Sistemi di Innovazione da Biomassa si sono realizzate successioni di funzioni diverse. Queste possono essere divise in cicli virtuosi e viziosi. Nel caso di cicli virtuosi la diffusione delle rispettive tecnologie e' stata un successo (ad esempio, la digestione di biomassa in Germania e la co-combustione di biomassa nei Paesi Bassi), mentre si osserva una lenta diffusione per quelle tecnologie (ad esempio la digestione di biomassa, la gassificazione di biomassa e la combustione isolata di biomassa nei Paesi Bassi) per le quali il sistema e' stato dominato da circoli viziosi. Per la digestione di biomassa in Germania e la co-combustione di biomassa nei Paesi Bassi si e' assistito a una situazione in cui le Funzioni di Sistema si sono rafforzate a vicenda e hanno a loro volta innescato ulteriori Funzioni. Le principali ragioni del successo della diffusione di tali tecnologie sono da attribuire al completamento di alcune Funzioni di Sistema come l' Orientamento della Ricerca, dovuto a legislazioni favorevoli, la Formazione del Mercato legata a sistemi di remunerazione redditizi, e le Attivita' Imprenditoriali per le quali gli imprenditori fanno gruppo, premono per condizioni istituzionali piu' vantaggiose, migliorano la tecnologia e mettono in piedi progetti. Grazie alla riuscita di queste Funzioni di Sistema, anche altre funzioni si realizzano, come lo Sviluppo e la Diffusione delle Conoscenze, la Mobilitazione di Risorse e la Formazione di Gruppi di Pressione. Un ulteriore risultato riguarda il fatto che il processo di innovazione delle tecnologie da biomassa non segue un modello lineare, ma comincia nella maggiore parte dei casi con la guida del governo al fine di aderire a obbiettivi internazionali o nazionali riguardanti il cambiamento climatico, la riduzione delle emissioni da CO_2 o il risparmio energetico.

Nel caso di tecnologie per le quali non sia avvenuta alcuna diffusione di rilievo, le Funzioni di Sistema completate senza successo hanno interagito fra di loro provocando un circolo vizioso, cosicché il relativo Sistema di Innovazione da Biomassa e' collassato. Nel caso della gassificazione di biomassa la mancanza di orientamento del governo e delle compagnie di energia ha provocato l' abbandono della tecnologia dopo appena un decennio di sperimentazione. Nel caso della digestione di biomassa, legislazioni inconsistenti e sfavorevoli e l' assenza di un mercato hanno impedito la diffusione di tale tecnologia. Per la combustione di biomassa la maggior parte delle Funzioni di Sistema e' stata completata con successo, ovvero la tecnologia era affidabile e dimostrata, quattro impianti di scala ridotta sono stati costruiti, tuttavia a causa dell' assenza di un mercato, la tecnologia non si e' affermata su larga scala.

Per rispondere alla domanda *'Come superare l'attuale situazione di lock-in da carbonio ed accelerare la diffusione di tecnologie di energia rinnovabile nella società?'* si può affermare quanto segue. I risultati dimostrano che le tecnologie da biomassa attraversano traiettorie di sviluppo, diffusione e implementazione di lungo termine (10-30 anni). Tuttavia, il governo olandese ha offerto solamente politiche di breve periodo e ha eliminato ogni supporto nel momento in cui i problemi tecnici non sono stati risolti in tale breve periodo. Al fine di accelerare la diffusione delle tecnologie di energia da biomassa, si rende necessario un orientamento del governo di lungo termine e stabile, nel quale vengano offerti tempo e possibilita' per sperimentazioni, si formi un mercato e gli imprenditori formino una lobby per ottenere condizioni istituzionali migliori per la loro tecnologia.

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Well, that's it then, the final chapter of this book that has been a fantastic four-year chapter of my life. The main hypothesis of my PhD thesis was that a technology trajectory could only be successful if certain System Functions are fulfilled. Well, after four years of being enrolled in the PhD trajectory, I could not only confirm this for technology trajectories but would actually propose that for a successful PhD trajectory certain 'Functions' have to be fulfilled as well!

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Simona Negro
Utrecht, 2006

Curriculum Vitae

Simona Negro was born in Milan, Italy, on 24 September 1978. She completed her secondary education at the European School of Munich (ESM) in Germany in 1996, with the subjects German, French, English, Italian, Mathematics, Chemistry, and Geography. In June 2001, she graduated as a Master in Chemistry from the Faculty of Chemistry at the University of Bath, United Kingdom. From 1998-1999, she carried out a one-year placement in industry at Shell Technology Exploration and Production, Rijswijk, The Netherlands. She worked as a trainee in the non-damaging drilling fluid team, where she carried out analyses to improve the properties of silicate drilling fluids by viscosity measurements, hot rolling, and micro-pressure transmission experiments.

In 2002, Simona graduated from the European Postgraduate Master Course in Environmental Management (EPCEM) at the Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, The Netherlands. During this Master course, a policy paper was written on "Energy Policy in Italy" (hosted by Fondazione Eni Enrico Mattei, FEEM in Milan, Italy). Furthermore, a group project at the IVM on "The role of Biomass in Carbon Flows between Eastern and Western Europe: Potential and Perspectives" and an individual internship at the Ministry of VROM, Directorate Strategy and Policy (SB), "Comparative Study between the Draft EU Directive and the Proposal of the National Commission on Emission Trading Schemes and Initial Allocation of CO_2 Emission Allowances" were completed.

In 2004, she started her PhD project entitled "Dynamics of Technological Innovation Systems – The Case of Biomass Energy" at the Innovation Studies group of the Copernicus Institute at Utrecht University. The PhD project was carried out within a larger research programme called 'BioPUSh' (i.e. Integrated Strategies for Identifying Optimal Bio-energy Production & Utilization Systems), financed by the NWO-NOVEM Energy Research Programme.

From 2006 to 2007, she will work in the same group as a Post-Doc within the frame of the NWO funded Environment & Economy programme called "Clusters for Innovation and Sustainability (CIS)".

Scientific Publications

Negro, S.O., M.P. Hekkert and R.E. Smits. (2007) "Explaining the failure of the Dutch innovation system from biomass digestion – A functional analysis". Energy Policy 35: 925-938

Hekkert, M.P., R.A.A. Suurs, S.O. Negro, S. Kuhlmann and R.E.H.M Smits. (2006) "Functions of Innovation Systems: A new approach for analysing technological change". Technological Forecasting and Social Change **In Press.**

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Negro, S.O. and M.P. Hekkert. (**submitted**) "System Functions Explaining Success or Failure of Emerging Technologies: A Longitudinal Comparative Case Study of Dutch and German Biomass Digestion Technology". Technology Analysis & Strategic Management

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Negro, S.O., Hekkert, M.P., Smits, R.E.H.M. "The evolution of biomass digestion technology in the Netherlands" pp 51-69. ASEM GriPP-Net Workshop "Current Development of Green IPPs: Experiences, Challenges, and Strategies". Karlsruhe September 15th, 2005.

Conference papers

Negro, S.O. and Hekkert M.P. "Benchmarking the Functions of Innovation Systems – The Success Story of the German Biomass Digestion Innovation System". SPRU 40th Anniversary Conference "The Future of Science, Technology and Innovation Policy", Brighton, UK, September 11-13, 2006.

Negro, S.O. and Hekkert M.P. "Benchmarking the Functions of Innovation Systems – The Success Story of the German Biomass Digestion Innovation System". EASST Conference "Reviewing Humanness: Bodies, Technologies and Spaces", Lausanne, Switzerland, August 23-26, 2006.

Negro, S.O., Suurs, R.A.A., Hekkert, M. P. "The bumpy road of Biomass Gasification in the Netherlands; Explaining the rise and fall of an emerging innovation system". Working paper on the DRUID website, DRUID Summer Conference 2006, Kopenhagen, Denmark, June 18-20, 2006

Negro, S.O., Suurs, R.A.A, Hekkert, M.P. "A Techno-Institutional Analysis of Energy Systems in Transition The Case of Dutch Biomass Gasification". Draft Paper presented at the 11th Annual International Sustainable Development Research Conference, June 6-8, 2005 Finlandia Hall, Helsinki, Finland

Negro, S.O., Suurs, R.A.A, Hekkert, M.P. "A Techno-Institutional Analysis of Energy Systems in Transition The Case of Dutch Biomass Gasification". Draft Paper presented at the EMAEE conference, Utrecht, The Netherlands, May 19-21, 2005

Negro, S.O., Hekkert, M.P., Smits, R.E.H.M. "On the dynamics of a technology specific innovation system: The case of biomass digestion technology in the Netherlands from 1974 until 2004". Draft paper presented at the DRUID PhD Winter Conference, Copenhagen, Denmark, January 26-29, 2005

Poster

Negro, S.O., Suurs, R.A.A, Hekkert, M.P. "Functions of Innovation Systems: A tool to evaluate the success chances of emerging technologies". Poster presented at the DRUID Summer Conference 2006, Copenhagen, Denmark, June 18-20, 2006.