Uncertainty and entrepreneurial action

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Uncertainty and entrepreneurial action

The role of uncertainty in the development of emerging energy technologies

Onzekerheid en ondernemersgedrag
De rol van onzekerheid in de ontwikkeling van opkomende energietechnologieën

(met een samenvatting in het Nederlands)

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Contents

List of figures

List of tables

Prologue

This PhD project is carried out within a larger research program called "Dealing with Uncertainties in the Transition to a Sustainable Energy System: An Integrative Approach", which is financed by the NWO-SenterNovem Energy Research Program. The overall aim of this research program is to develop an integrated approach for assessing and dealing with uncertainties in the transition towards a sustainable energy system. The long-term policy goal to achieve a more sustainable energy system has led to significant changes in the Dutch energy sector. Both public and private decision makers in this sector are confronted with great uncertainties regarding the large number of options that could be envisaged on the longer term (i.e. different visions on how to achieve a more sustainable energy system) and the various factors influencing these options (i.e. changes in energy demand, institutional changes, technical developments, etc.). In present practice, many of these uncertainties are ignored or dealt with in an ad-hoc manner, or no decisions are taken at all because of uncertainties about what the best strategy is. This research program aims to improve this situation by developing an approach that will help decision makers in the Dutch energy sector to identify and deal with the various uncertainties regarding the transition to a sustainable energy system.

The research program consists of two PhD projects and one Post-Doc project. The main goals of the Post-Doc project (carried out at the Policy Analysis department of Delft University of Technology) are to integrate the outcomes of the PhD projects and to develop policy strategies for stimulating the transition towards a more sustainable energy system. The PhD projects each use a different but complementary approach for identifying important uncertainties and analyzing how these uncertainties influence the overall transition towards sustainability. The other PhD student (affiliated to the department of Science, Technology and Society of Utrecht University) focuses on a techno-economic analysis of different options to make the energy system more sustainable and the uncertainties that each of these options entails. However, the successful implementation of these sustainability options is highly dependent on the decisions and actions of the various actors involved. Whether or not different actors will decide to develop and implement more sustainable energy innovations is, in turn, influenced by the uncertainties that these actors perceive. Therefore, this PhD project applies an innovation perspective to analyze which types of uncertainties play a key role in the decisions and actions of the various actors involved in the transition towards a more sustainability energy system in the Netherlands. This project is carried out at the department of Innovation and Environmental Sciences of Utrecht University and the department of Policy, Organisation, Law & Gaming of Delft University of Technology.

1 Introduction

1.1 Background and relevance

The energy sector is subject to various forces of change. The most fundamental force of change is the increasing awareness among scholars, policy makers and society at large of the environmental problems caused by the existing energy system. The existing energy system is strongly dependent on fossil fuels such as oil, natural gas and coal. The environmental consequences of the large-scale use of fossil fuels, including global climate change, local air pollution and acidification, are currently receiving much attention. In order to counteract these environmental problems and achieve a more sustainable future, a major transformation of the energy sector is needed. Transformations like these take at least one generation and involve mutually interacting developments in different domains such as economy, technology and politics (Rotmans, Kemp et al. 2000). The terms 'transition' and 'socio-technological transformation' have been used to describe these long-term change processes (Geels 2002a; Geels 2002b; Rotmans 2003; Elzen, Geels et al. 2004; Elzen and Wieczorek 2005; Smith, Stirling et al. 2005).

To create a sustainable energy system, new technologies that are more sustainable than the existing technologies need to be developed and implemented on a large scale. More sustainable technologies include both energy-efficient technologies (i.e. technologies that still use fossil fuels, but more efficiently than the existing technologies) as well as renewable energy technologies (i.e. technologies that are fuelled by renewable energy sources like wind, biomass, hydropower or solar power). However, despite the policy ambitions to reduce the use of energy and increase the share of renewable energy sources, these more sustainable energy technologies have trouble breaking through. To accelerate the transition to a more sustainable energy system, it is important to understand how more sustainable energy technologies are developed and implemented and which factors influence this process.

Previous studies on the transformation of the energy system have demonstrated that the success of new, more sustainable energy technologies is not only determined by technical and economic factors (such as technical performance or the relative price of the technology), but also by the social system in which the technology is embedded (Jacobsson and Johnson 2000; Jacobsson and Bergek 2004; Negro 2007). Various types of actors (including, among many others, producers and users of knowledge and technology) and institutions (that define the rules and regulations shaping the behaviour of actors) influence the development and implementation of the new technology. The technological developments, in turn, shape the behaviour of the actors and the institutional setting. Thus, the development and implementation of new technologies can best be understood as a highly complex process in which technological change and social change interact and mutually influence each other. To analyze this process, this thesis applies an innovation perspective, as this perspective includes techno-economic as well as many other factors influencing the development and implementation of new technologies.

Innovation processes involve a large diversity of actors, who each fulfil different roles in the development and implementation of new technologies. A crucial role is the role of the entrepreneur. Entrepreneurship involves the discovery, creation and exploitation of opportunities (Garud and Karnøe 2003). The role of the entrepreneur in the development and implementation of new technologies is to turn the potential of new knowledge, networks and markets into concrete actions to generate and take advantage of new business opportunities (Hekkert, Suurs et al. 2007). Through their actions, entrepreneurs help to turn the outcomes of basic R&D activities into commercial technological products to be implemented on a large scale. In the innovation literature, there is a growing awareness that the development and implementation of new technologies cannot be attributed to any one individual actor, but is best understood as "*both an individual and a collective act*" (Van de Ven 1993; Edquist 2001; Garud and Karnøe 2003; Jacobsson and Bergek 2004; Hekkert, Suurs et al. 2007). As Garud and Karnøe argue, "*technology entrepreneurship is a larger process that builds upon the efforts of many*" (Garud and Karnøe 2003, p. 277). This implies that the role of the entrepreneur is not fulfilled by a single actor, but by multiple, different types of actors. Entrepreneurs can be technology developers producing new technologies, as well as, for instance, adopters (buyers and users) who offer critical inputs for the commercialization of new technologies (Van de Ven 1993; Garud and Karnøe 2001; Garud and Karnøe 2003). In addition, entrepreneurs can be both new entrants aiming to pursue business opportunities in new markets, as well as incumbent companies wanting to diversify their business strategy to take advantage of new technological developments (Hekkert, Suurs et al. 2007). Since the actions of these various types of entrepreneurs to a large extent determine whether or not more sustainable energy technologies are successfully developed and implemented, it is very important to gain a better understanding of the underlying factors that influence the innovation decisions and actions of entrepreneurs.

An important characteristic of innovation decisions is that they inherently involve many uncertainties (Nelson and Winter 1977; Dosi 1982; Rosenberg 1996; Edquist 1997; Smits and Kuhlmann 2004). This is particularly true for innovation decisions concerning emerging technologies; i.e. technologies that are still in an early stage of development (Van Merkerk and Van Lente 2005). On the one hand, the high degree of uncertainty surrounding emerging technologies signifies the large range of opportunities that a new technology has to offer. On the other hand, however, this uncertainty may pose a threat of not knowing what comes next and not being able to determine *ex ante* the success or failure of a technological path (Garud and Rappa 1994). In other words, uncertainty can both stimulate and discourage entrepreneurs in terms of developing and implementing emerging technologies. This makes uncertainty an important factor influencing the innovation decisions and actions of entrepreneurs. Since entrepreneurial action is considered to be an important determinant of the development and implementation of emerging, more sustainable energy technologies, gaining insight into the role of uncertainty in entrepreneurial action will help us to better understand the development and implementation of these technologies.

Reviewing the literature on uncertainty, it becomes clear that there is no consensus on the conceptualization of uncertainty (Duncan 1972; Gifford, Bobbitt et al. 1979; Jauch and Kraft 1986; Sutcliffe and Zaheer 1998; Kreiser and Marino 2002; Van Geenhuizen and Thissen 2002; Walker, Harremoes et al. 2003). In this thesis, the term 'uncertainty' is defined broadly as "*any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system*" (Walker, Harremoes et al. 2003, p. 5). The definition applied here includes both the more narrowly defined concepts of 'risk' (defined as randomness with knowable probabilities; i.e. situations in which probabilities that certain future states will occur are precisely known) and 'uncertainty' (defined as randomness with unknowable probabilities; i.e. situations in which probabilities are not precisely known) (Knight 1946). In the literature, the concept of uncertainty is measured in various ways. A common distinction is made between objective uncertainty versus perceived uncertainty (Jauch and Kraft 1986; Kreiser and Marino 2002). Supporters of the objective view on uncertainty define uncertainty as a characteristic of the environment that can be measured objectively (Dess and Beard 1984). Supporters of the perceptive view on uncertainty argue that uncertainty is dependent on the individual and cannot be measured objectively (Milliken 1987). Frances Milliken defines perceived uncertainty as "*an individual's perceived inability to predict something accurately*" (Milliken 1987, p. 136). The term 'perception' refers to the process by which individuals organize and evaluate stimuli from the environment. The existence of information itself lacks meaning until an individual perceives it (Corrêa 1994). Environments are therefore neither certain nor uncertain but are simply perceived differently by different actors. Since the interest of this thesis lies in the innovation behaviour of the various actors involved in the development and implementation of emerging, more sustainable energy technologies, the perceptive view on uncertainty would seem most suitable. After all, the behaviour of actors is principally determined by their perceptions of uncertainty, rather than by objective uncertainty. Therefore, in the remainder of this thesis, 'uncertainty' refers to 'perceived uncertainty'.

Despite the widely acknowledged importance of uncertainty in innovation literature, some authors argue that the uncertainty concept is still poorly elaborated in innovation studies (Fleming 2001; Corral 2002). As Lee Fleming states: "*While the course of technological change is widely accepted to be highly uncertain and unpredictable, little work has identified or studied the ultimate sources and causes of that uncertainty.*" (Fleming 2001, p. 117) Fleming argues that most research gives the uncertainty topic only brief consideration en route to other issues, and that little work has attempted to identify and empirically validate the causal sources of uncertainty (Fleming 2001). A similar argument is put forward by Carlos Montalvo Corral, who states that: *"In the literature on technological change 'uncertainty' is considered to be the central dimension that 'organises' innovative activities. Surprisingly, despite such importance, there is an absence of studies that clearly define and specify the sources of uncertainty in innovation projects."* (Corral 2002, p. 68) To contribute to the work in this field, this thesis will attempt to develop a typology of perceived uncertainties that is suitable for analyzing innovation decisions. This uncertainty typology will be applied in multiple empirical cases on the development and implementation of emerging, more sustainable energy technologies. Performing these empirical case studies is not only useful to empirically validate the uncertainty typology, but also helps determine which of the different types of perceived uncertainty play a dominant role in the development and implementation of these technologies.

However, knowing which types of perceived uncertainty play a dominant role is just a first step in gaining a better insight into the influence of perceived uncertainty on the development and implementation of emerging, more sustainable energy technologies. The next step is to analyze how these uncertainties influence the innovation decisions and actions of the entrepreneurs involved. Several authors have argued that uncertainty is one of the major barriers hampering the breakthrough of emerging, more sustainable energy technologies (Kemp, Schot et al. 1998; Rotmans 2003; Jacobsson and Bergek 2004; Foxon, Gross et al. 2005). More specifically, Jacobsson and Bergek (2004) argue that uncertainty is blocking the development and implementation of more sustainable energy technologies, since it hinders the fulfilment of entrepreneurial activities (Jacobsson and Bergek 2004). Since the development and implementation of emerging, more sustainable energy technologies cannot take place without entrepreneurs who dare to take action, this argument by Jacobsson and Bergek emphasizes once more the important impact of uncertainty on the success of these technologies. However, the above-mentioned studies mainly focus on the system level and provide little insight into the perspective of the entrepreneurs.

Another strand of innovation literature applies a firm-level perspective in order to study how uncertainty influences innovation. Within the firm-level studies, a distinction can be made between studies that focus on the influence of uncertainty on the *development* of new (technological) products and studies that focus on the *adoption* of new technologies. In the New Product Development (NPD) literature, much attention has been paid to the effect of uncertainty on the development process and on the success of new products (e.g. Griffin and Hauser 1996; Mullins and Sutherland 1998; Souder, Sherman et al. 1998; Bstieler and Gross 2003). The aim of most of these studies is to determine which strategies (in terms of different approaches to scanning potential markets, distinctive levels of R&D/market integration or different learning strategies) are most effective for firms in reducing the uncertainties encountered in new product development. The adoption studies, in turn, have developed important insights into the problem of optimal timing in adopting a new technology under uncertainty, by modelling the dilemma that firms face when having to weigh the costs of adopting too soon ('sunk costs' which cannot be recovered) against the opportunity costs of waiting in anticipation of better future technologies (e.g. Mamer and McCardle 1987; Saha, Love et al. 1994; Farzin, Huisman et al. 1998; Marra, Pannell et al. 2003; Doraszelski 2004). One of the outcomes of these studies is that, even though new technologies might be superior to the established technologies, firms are very hesitant to adopt new technologies because of the various uncertainties they perceive (Farzin, Huisman et al. 1998). However, despite their valuable outcomes, these studies do not provide sufficient insight to understand the role of uncertainties in emerging, more sustainable energy technologies. A principal shortcoming of these studies is that they mainly focus on *individual* firms that are either developing or adopting a new technological product. As argued above, the development and implementation of emerging, more sustainable technologies involves multiple, different types of firms: developers as well as adopters of the new technologies. Moreover, the development and adoption of emerging energy technologies does not follow a sequential pattern, but instead one could speak of a co-evolution process between technology development and adoption practices. This implies that the actions of technology developers and adopters mutually influence each other in the early phases of the technology life cycle. Therefore, a second issue which is addressed in this thesis is to analyze how perceived uncertainties influence the interrelated entrepreneurial actions of both technology developers and adopters.

In this thesis, the influence of perceived uncertainty on the development and implementation of emerging, more sustainable energy technologies will be studied in multiple case studies that each focus on a specific technology. An important criterion for selecting the cases is the development phase of the technology. The reason for this is that the literature on technology or industry life cycles argues that uncertainty is high in the early stages of technology development and decreases in later stages, as a technology matures and a dominant design emerges (Tushman and Rosenkopf 1992; Afuah and Utterback 1997; St John, Pouder et al. 2003; Taminiau 2006). Based on these studies, one may expect that the influence of perceived uncertainty on the development and implementation of more sustainable energy technologies will vary between technologies that are in different phases of development. Since the explanatory power of the above-mentioned life cycle studies concerns the technology or industry more than the entrepreneurs, it is worthwhile analyzing whether or not the uncertainties perceived by the entrepreneurs differ between technologies that are in different phases of development. Furthermore, it is worthwhile exploring whether and how the effect of perceived uncertainties on entrepreneurial action differs in subsequent technology development phases. By studying technologies that are in different phases of development, this thesis attempts to develop new insights into these issues.

In reaction to the growing awareness of the environmental problems caused by our existing energy system, there is a strong need to influence and accelerate the development and implementation of more sustainable energy technologies. Due to the high level of uncertainty, policy-makers and entrepreneurs still puzzle over how best to manage these innovation processes. Although the development of appropriate steering arrangements to stimulate these innovation processes is such a complicated issue that it deserves a research of its own, the final challenge addressed in this thesis is to use the outcomes of this research to formulate lessons for policy and management.

Thus, the central aim of this thesis is to gain a better understanding of the role of perceived uncertainties in the development and implementation of emerging, more sustainable energy technologies. More specifically, the aims of this thesis are:

- to identify and analyze different types of perceived uncertainty with respect to emerging, more sustainable energy technologies
- to analyze the influence of these perceived uncertainties on the actions of the various entrepreneurs involved
- to gain insight into the differences in perceived uncertainties and in the influence of perceived uncertainties on entrepreneurial action for technologies in subsequent phases of technology development
- to formulate lessons for policy and management.

In the following section, the research design is discussed, cases are selected and the above-mentioned research aims are specified further as research questions.

1.2 Research design

The central aim of this thesis is to gain a better understanding of the role of perceived uncertainties in the development and implementation of emerging, more sustainable energy technologies. As the preceding discussion of the research field made clear, still relatively little is known about this issue. This research is thus of an exploratory nature. For that reason, it is not aimed at testing any hypotheses or propositions, but aims instead to develop new theoretical and empirical insights. An appropriate research strategy to investigate unexplored research areas is to use case studies (Eisenhardt and Graebner 2007). This section therefore starts with a description of the main characteristics of the case study approach (1.2.1). Then, three important elements of the research design, i.e. the theoretical exploration, the case selection and the data collection, are discussed in more detail (Section 1.2.2 to 1.2.4). The section concludes with the formulation of research questions (1.2.6).

1.2.1 Case study research

Case study research involves the examination of a phenomenon in its natural setting. The method is especially appropriate in new research areas, with a focus on "how" or "why" questions concerning a temporary set of events over which the researcher has little or no control (Yin 2003). Additional advantages of case study research are that case studies are particularly suitable for the analysis of relations, actions and interactions of various actors involved in a social system and to identify different perceptions (Swanborn 2000). For these reasons, case study research is considered an appropriate research strategy for the research aim of this thesis.

A distinction can be made between a single case design and a multiple case design. This research applies a multiple case design, consisting of four cases. A multiple case design is generally considered a more robust design than a single case study (Yin 2003; Eisenhardt and Graebner 2007). The main reason for this is that multiple cases provide for the observation and analysis of a phenomenon in several settings (Eisenhardt and Graebner 2007). As a result, multiple cases deliver more precise definitions of constructs and relationships and more reliable theoretical propositions (Eisenhardt and Graebner 2007). However, a multiple case design calls for a more complicated case selection procedure than a single case design. Whereas the case selection of a single case design is based primarily on the uniqueness of the case, the case selection of a multiple case design is based on theoretical reasons ('theoretical sampling') (Eisenhardt 1989). Central to this selection procedure is 'replication logic'. Like a series of laboratory experiments, multiple cases are discrete experiments that serve as replications of or contrasts or extensions to the emergent theory (Yin 2003; Eisenhardt and Graebner 2007). The goal of theoretical sampling is to choose cases that are likely to either replicate the emergent theory (that is: the case is expected to yield similar results as previous cases) or extend the emergent theory (that is: the case is expected to yield different results but for reasons predicted by the theory). Thus, an important feature of multiple case study research is a careful selection of cases on the basis of theoretical arguments, so as to allow for replication logic.

However, although this selection procedure calls for careful preparation before entering the field, this does not imply that the research design is fixed. In fact, an important feature of case study research is the flexibility to make adjustments during the data collection process (Eisenhardt 1989). The flexibility to make adjustments to the research design allows the researcher to probe emergent themes or to take advantage of special opportunities that a given situation may present (Eisenhardt 1989). Important discoveries that occur during the conduct of a case can lead to a reappraisal of the case selection or of the theoretical framework underlying the cases. As a result, researchers can decide to make adjustments to the selection of cases (e.g. adding or replacing a case) or to the data collection procedure (e.g. adding questions to the interview protocol). In research aimed at producing summary statistics about a set of observations, such adjustments are not legitimate. However, in case study research it makes sense to adapt the case study design if these alterations in data collection are likely to provide new or better theoretical insights (Eisenhardt 1989). Robert Yin even argues that if researchers do *not* make adjustments in case of important discoveries that do not suit the original design, they can be accused of distorting or ignoring data just to accommodate the original design (Yin 2003, p. 51). Thus, the research strategy is highly iterative in the sense that the researcher moves back and forth between research design, data collection and data analysis. Figure 1-1 offers a graphical representation of the research design. The adjustments of the research design are represented by the dotted line between the design stage and the data collection and analysis stage.

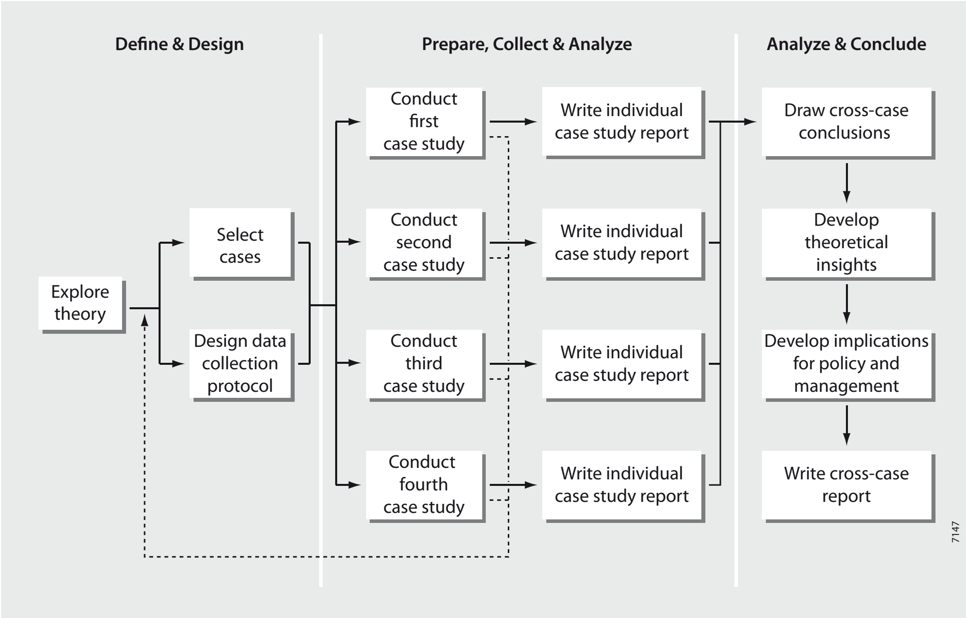

Figure 1-1 Graphical representation of the research design (adapted from COSMOS Corporation as reported in Yin 2003).[1]

In order to know what data to collect and how to analyze the data, a careful design of the research is very important. As Figure 1-1 shows, the design phase consists of three elements: explore theory, select cases and design a data collection protocol. Another important element in Figure 1-1 is the data analysis. In the following sections, these elements are discussed in more detail.

1.2.2 Theoretical exploration

The first research step (see Figure 1-1) is a theoretical exploration of the role of perceived uncertainties in the development and implementation of emerging, more sustainable energy technologies. The purpose of this step is to define more clearly what is to be examined, in order to have a sufficient blueprint for determining what data to collect and how to analyze the data (Yin 1981; Yin 2003).

The theoretical exploration included a broad range of scientific literature on the topics:

- socio-technological transition (or related concepts such as 'system innovations', 'socio-technological transformations'), phases of technology development, typology of actors involved in socio-technological transitions
- uncertainty in general, perceived uncertainty, typologies of uncertainty, uncertainty and innovation, uncertainty and entrepreneurial action, uncertainty in relation to the development and implementation of more sustainable energy technologies.

The literature exploration resulted in a preliminary theoretical framework. The core of this framework consists of a typology of perceived uncertainty. Theoretically defining a typology of perceived uncertainty helps determine how to empirically measure perceived uncertainty. As argued in the introduction (see Section 1.1), entrepreneurial action is of crucial importance to the development and implementation of emerging, more sustainable energy technologies. Since the role of entrepreneur can be fulfilled by different types of actors, it is important to acknowledge that different types of actors can have different perceptions of uncertainties and can respond differently to the perceived uncertainties. As furthermore argued in the introduction, perceived uncertainties may differ between different technology development phases. Therefore, the next step in the construction of the theoretical framework was to relate the typology of perceived uncertainties to different technology development phases and different types of actors. The theoretical framework is reported in Chapter 2.

1.2.3 Case selection

The thesis consists of four case studies that each focus on the development and implementation of an emerging, more sustainable energy technology. In order to facilitate comparison across the cases, all case studies focus on the Netherlands. Apart from practical criteria (such as easy access to information), a theoretical criterion for selecting the cases was to include cases that are in different phases of technology development. As argued in Section 1.1, it is expected that perceptions of uncertainty and the influence of perceived uncertainty on entrepreneurial action differ for technologies in different phases. Based on the evolutionary approaches to innovation that describe technical change according to the analogy of life cycles (e.g. (Nelson and Winter 1977; Tushman and Rosenkopf 1992; Utterback 1994)), transitions or the underlying technological trajectories can be simplified and divided into four phases (Rotmans, Kemp et al. 2001; Van Lente, Smits et al. 2003):

1. pre-development
2. take-off
3. acceleration
4. stabilization.

The pre-development phase is characterized by basic R&D activities in which various routes and options are suggested and tried. Technological variety is large, since various technology developers work on competing products. The take-off phase is characterized by strong competition. Now that the emerging technology has entered the market, the technology has to compete with both established technologies as well as with other new technologies (Tushman and Rosenkopf 1992) (Utterback 1994). The acceleration phase is the phase in which the new technology becomes more and more embedded. Typical for the acceleration phase is that the growth in the number of products is often accompanied by a shake-out with respect to the number of technology developers (Utterback 1994). The final phase is the stabilization phase, in which the new technology has become so entrenched in current routines, infrastructure and legal frameworks that it has become an established technology. In this phase, most changes are incremental and build on economies of scale.[2]

One way to determine the current development phase of an emerging technology is to use the indicators displayed in Table 1-1 (Suurs, Hekkert et al. 2004).[3]

Since this thesis focuses on the development of emerging technologies, only the first three phases (pre-development, take-off and acceleration) are considered. The final phase (stabilization) is not included, as the technologies that have reached this phase have become entrenched in the socio-institutional system and should therefore no longer be labelled as 'emerging' but as 'established' technologies.

Table 1-1 Indicators for the technology development phases.

Phase	Indicator
Pre-development	Prototype development
Take-off	Early adopters start buying the technology
Acceleration	Strong diffusion of the new technology
Stabilization	Saturated market demand

Based on these criteria, the following four technologies were selected.[4]

The first case focuses on micro-CHP (Combined generation of Heat and Power on domestic scale). The use of micro-CHP can lead to substantial energy savings and carbon emission reduction, since the overall efficiency is higher compared to generating space heating, hot water and electricity separately. In addition, because of the decentralized generation of electricity, distribution loss can be avoided. Micro-CHP is still in the pre-development phase, since prototypes are being developed but the technology has not yet entered the Dutch market (see Table 1-2). Micro-CHP is an interesting case to study, since expectations regarding the potential contribution of micro-CHP to the transition towards a more sustainable energy system are high and many initiatives are currently being developed in the Netherlands.

The second case focuses on biofuels. Biofuels are liquid fuels produced from biomass and used for transport purposes. A distinction can be made between first- and second-generation biofuels. The first-generation biofuels is produced with commercially available technologies to convert sugars and canola oils into biofuels. The second-generation biofuels involves the conversion of woody biomass into biofuels, and is produced with advanced chemical or enzymatic technologies that are not yet commercially available. The advantages of the second-generation biofuels are that much higher volumes of biofuel can be obtained from one acre of land, and that the carbon emission reductions are much higher (minus 90%) compared to the first-generation biofuels (e.g. minus 30%) (Suurs and Hekkert 2005; Faaij 2006). In the biofuel case, the activities from 1990 until 2005 are described. Within this period, the first-generation and second-generation biofuel technologies have slowly progressed from the pre-development phase towards the take-off phase. Although the first experiments with producing and implementing different biofuels in the Netherlands date from the early 1990s, it is not until recently (from 2005 on) that a market has begun to develop. Therefore, in the period studied both generations of biofuel technologies were still in the pre-development phase (see Table 1-2).

The third case focuses on biomass gasification. Gasification is a thermo-chemical process technology that converts biomass (usually wood residues, waste wood or manure) into a combustible gas. The produced gas (consisting mainly of CO and H_2) can be burned for heat or steam supply or it can be used in secondary conversion technologies (such as gas turbines or engines) to produce electricity. The advantage of gasification is that much higher electrical efficiencies can be reached (35-40%) compared to combustion power plants (25-30%) (Williams and Larson 1996; Faaij, van Ree et al. 1997). Therefore, the implementation of biomass gasification can make a substantial contribution to realising a more sustainable energy system. However, gasification is technologically more complex than combustion and only a few projects in Europe so far have achieved a commercial status (Kwant and Knoef 2004; Faaij 2006). In the Netherlands, many activities have been taking place with regard to biomass gasification technology, but the

Table 1-2 Overview of the cases and their technology development phase.

Case	Phase
Micro-CHP	Pre-development
Biofuels	Pre-development
Biomass gasification	Take-off
Biomass combustion	Acceleration

number of adopters is still very limited. Thus, biomass gasification is still at the beginning of the take-off phase (see Table 1-2).

The fourth and final case concerns biomass combustion. Biomass combustion is considered an appealing solution in terms of the overall goal of achieving a more sustainable energy system, as it is a relatively simple technology to convert biomass into electricity and heat. In the combustion process, biomass (usually wood residues, waste wood or manure) is combusted to produce steam. The steam can be used for heating purposes and for the production of electricity (via a steam turbine). Although the electrical efficiency of biomass combustion is lower compared to other thermo-chemical conversion technologies (like gasification or pyrolysis), the main advantage of biomass combustion is that the technology is in a more mature stage of development compared to the other technologies (Energie- en Milieuspectrum 1997; BTG 2005; IEA Bioenergy 2006). Over the past years, the number of operational biomass combustion plants and the installed (thermal and electrical) capacity have been increasing steadily in Europe, including the Netherlands. This strong diffusion indicates that biomass combustion has entered the acceleration phase (see Table 1-2).

1.2.4 Data collection

Before entering the field, each of the case studies started with the design of a case study protocol. The aim of a case study protocol is to guide the researcher in carrying out the data collection and to increase the reliability[5] of the case study research (Yin 1981). The protocol consisted of the following elements:

- overview of the case study: including a brief description of the case to be studied (description of the main technological features, the key actors involved, important historical events, etc.), the specific case study objectives and questions, and the conceptual framework for the case study
- data collection method: the data collection consists of interviews and/or a literature review. In preparation for the interviews, a list of potential interview candidates is compiled and an interview scheme (in which the research questions and theoretical concepts are translated into interview questions) is designed.

Most of the data for the case studies on micro-CHP, biomass gasification and biomass combustion was obtained by conducting interviews with the key actors involved in each of the cases. In total, thirty-five in-depth interviews were held (for an overview of the interviewees, see Appendix A). Apart from two interviews which were conducted over the telephone, all interviews were face-to-face. The interviews were semi-structured in the sense that the questions from the interview scheme were complemented with additional questions that arose during the interviews. The interviews contained both open and closed questions. The closed questions (such as the ranking and rating of different types of uncertainties) were mainly used to identify which types of perceived uncertainty were most important. The open questions were used to gain insight into the "why" questions (e.g. "Why does the actors decide to invest in the emerging technology?", "Why do the actors perceive uncertainty about a specific subject?", "Why do perceptions of uncertainty differ between the actors?", and so on). From each of the interviews, a transcript was made which was sent back to the interviewees for verification. Further details about the selection of the interviewees and the interview questions for each of the case studies are given in the empirical chapters (Chapters 3-6).

One of the main advantages of interviews is that information can be gathered on perceptions and strategies of actors, which would be difficult to obtain from other sources. Therefore, interviews are an essential source of information for this research. However, the drawback of interviews is that selective or biased answers can be given. This is especially the case for interviews about historical events (such as projects that took place several years ago). To avoid this drawback as much as possible, the data of an interview was combined with data from other interviews and with information from various types of documents (including policy documents, scientific articles, project reports, professional journals and newspaper articles). Since each source of data has its own strengths and weaknesses, combining multiple sources of data ('data triangulation') strengthens the validity of the case study evidence (Yin 1981; Eisenhardt and Graebner 2007).

The data collection method for the biofuels case differed from the cases mentioned above. The data for the biofuels case was based on an extensive review of grey literature (newspaper articles, professional journals and policy documents), reported in (Suurs and Hekkert 2005). The literature study resulted in a chronological overview of activities developed by the various actors (i.e. governmental institutions, entrepreneurs) involved in the development of biofuels in the Netherlands from 1990 to 2005. This chronological overview was used to analyze how various steering initiatives by the Dutch government have influenced the perceived uncertainties and behaviour of the actors involved. Due to time constraints, no additional interviews were conducted.

1.2.5 Data analysis

The least developed and most difficult aspect of case study research is the analysis of case study data (Yin 1981; Eisenhardt 1989). Although there are many different approaches to analyzing data, the overall idea is to examine and recombine case study evidence in order to address the initial research objectives.

Three general strategies for analyzing case study data are (Yin 2003):

- relying on theoretical propositions
- considering rival explanations
- developing a case description.

According to Yin, the most preferred strategy is to follow the theoretical propositions that led to the case study (Yin 2003).[6] However, in exploratory research, the existing knowledge base may be poor and the available literature may not provide any conceptual framework or theoretical propositions of note. Nevertheless, Yin argues that even exploratory case studies should be preceded by statements about what is to be explored, the purpose of the exploration, and criteria for interpreting the findings (Yin 2003). A second strategy for analyzing case study data is to consider alternative explanations for the case study findings. This can be done by comparing the findings with conflicting literature. Addressing rival explanations strengthens confidence that the case study findings are valid and helps to define more specifically to what domain the case study findings can be generalized. According to Eisenhardt, comparing the findings with literature discussing *similar* findings is, for the same reasons, important as well (Eisenhardt 1989). A third analytical strategy is to develop case study descriptions. A descriptive approach may help to structure the often enormous amount of data and to identify the appropriate causal links to be analyzed. (Eisenhardt 1989; Yin 2003)

In this research, all three analytical strategies were applied. The data analysis consisted of two steps. First, each of the four cases was analyzed individually ('within-case analysis'). This analysis was partly 'theory-driven', in the sense that the case data were structured and analyzed according to the preliminary theoretical framework described in Section 1.2.2. However, for the greater part, the analysis was 'inductive' in the sense that the analysis aimed to recognize patterns in the empirical data. This was done on the basis of detailed case descriptions. The outcomes of each case study were reported (see Figure 1-1, 'write individual case study report') and, when necessary, adjustments were made to the case study design before entering the following case study (see dotted feedback line in Figure 1-1). Second, a cross-case analysis was performed in order to identify patterns across the cases (see Figure 1-1). The cross-case analysis focused on three of the four case studies: micro-CHP, biomass gasification and biomass combustion. Since the data collection procedure of the biofuels case differed from the other cases (see Section 1.2.4), the biofuels case was not taken into account in the cross-case comparison. Nevertheless, as the micro-CHP case was in the same technology development phase as the biofuels case, the third research aim (i.e. gaining insight into the differences between technologies in different phases of development, see Section 1.1) could still be addressed. From the outcomes of the within-case analysis plus the cross-case analysis, overall impressions emerged. These impressions were compared to both conflicting and similar findings in the existing literature on the development of emerging technologies so as to increase confidence in the theoretical insights which were derived from the case study findings ('develop theoretical insights', see Figure 1-1). Finally, the findings were used to formulate lessons for policy and management.

1.2.6 Research questions

The aim and focus of this research project, as defined above, can be further specified in the following research questions:

RQ1: *What are the dominant types of uncertainties as perceived by the various entrepreneurs involved in the development and implementation of micro-CHP, biofuels, biomass gasification and biomass combustion in the Netherlands?*

RQ2: *How do perceived uncertainties influence entrepreneurial action and thereby the development and implementation of these technologies?*

RQ3: *What general insights can be derived from the cases studied with respect to the influence of perceived uncertainty on entrepreneurial action in subsequent technology development phases?*

RQ4: *What are the implications for policy and management?*

1.3 Thesis outline

The remainder of this thesis consists of six chapters. Chapters 2-5 were originally written in article format. To increase the coherence of the thesis, 'interludes' in-between the chapters explain how the following chapter builds on the previous chapters. As argued above (see Section 1.2.1), an important feature of case study research is the flexibility to make interim adjustments to the research design. These interim changes are also reported in the interludes.

Chapter 2 introduces a theoretical framework for studying the role of perceived uncertainties in socio-technological transformations (also called: 'transitions'). The framework consists of several building blocks: a typology of actors, a distinction between different technology development phases and a typology of perceived uncertainties.

Chapters 3 to 6 present the results of the four case studies. The first empirical case focused on micro-CHP. The goal of this first case study was twofold. The first objective was to analyze whether the theoretical framework (introduced in Chapter 2) was applicable in an empirical context. The results with respect to this first objective are reported in Interlude A. The second objective was to analyze the role of perceived uncertainties in the development of micro-CHP. With respect to the second objective, the first step was to analyze which types of perceived uncertainties played a dominant role in the innovation decisions of the various actors involved. The second step was to analyze how the different actors reacted to these perceived uncertainties and if this actor behaviour stimulated or hindered the overall transition. The empirical outcomes of the micro-CHP case are reported in Chapter 3.

Chapter 4 combines the outcomes of the micro-CHP case with the outcomes of the second case study on biofuels. The case study design of the biofuels case differed from the micro-CHP case (see Interlude B); whereas the micro-CHP case analyzed various sources of perceived uncertainty, the biofuels case focused exclusively on one source of uncertainty which proved to play a dominant role: political uncertainty. Furthermore, whereas the micro-CHP case provided a 'static' view of perceived uncertainties, in the biofuels case a first attempt was made to incorporate a more dynamic view on how perceived uncertainties and actor behaviour evolve over time. A chronological overview of the developments of biofuels in the Netherlands from 1990 to 2005 was used as a basis for this analysis. Together, the micro-CHP case and the biofuels case reveal an interesting picture of the influence of governmental behaviour on the perceived uncertainties and actions of entrepreneurs involved in the development of these emerging technologies.

The third case study, reported in Chapter 5, focuses on the development and implementation of biomass gasification. Since the biofuels case had shown that the perceived uncertainties and actions of entrepreneurs differed over time, the biomass gasification case aimed to provide a better understanding of how such changes come about (see Interlude C). Therefore, a more dynamic theoretical model was introduced. This model was used to analyze the role of perceived uncertainties in entrepreneurial projects aimed to develop and implement biomass gasification plants.

The final case study, reported in Chapter 6, focused on the development and implementation of biomass combustion. The case study design was identical to the biomass gasification case (see Interlude D). As the biomass gasification case had demonstrated that interactions between different types of uncertainties and various factors in the project environment largely influenced the decision of entrepreneurs whether or not to continue with their projects, the analysis of the biomass combustion case paid special attention to the identification of these interactions.

Chapter 7 aims to synthesize the findings of the preceding chapters and to reflect on the quality of the research design. Chapter 7 starts with a cross-case comparison, which will help to answer research questions 1 and 2. The answer to research question 3 will emerge by comparing the empirical outcomes of this study to the existing literature.

The final chapter (Chapter 8) discusses the implications for policy and management, thereby answering research question 4.

Notes

1 In the figure of Yin (2003), the steps 'explore theory' and 'develop theoretical insights' are respectively called 'develop theory' and 'modify theory'. However, the figure of Yin was not specifically adapted to exploratory case study research. The aim of exploratory case study research is not to test and modify theory, but to develop theoretical insights inductively from case study evidence. Therefore, the initial step is described here as a theoretical exploration and the later step as the development of theoretical insights.

2 For a more detailed description of the phases, see Chapter 2.

3 Another, more precise but also more complicated, way of determining the current transformation phase of a technological trajectory, is to draw a diffusion-curve and compare this curve to the S-curve of technological development (see Figure 2-2 of Chapter 2).

4 Note that the case studies do not intend to pass judgments on the techno-economic performance, environmental benefits or social desirability of these technologies. The goal of the case studies is to analyze how perceived uncertainties influence entrepreneurial action. As argued in Section 1.1, the underlying assumption of this thesis is that the development and implementation of these technologies cannot take place without the active involvement of entrepreneurs. Therefore, the initiation and continuation of entrepreneurial action are in the case studies valued as 'positive' whereas termination or a lack of entrepreneurial action is valued as 'negative'.

5 Increasing the reliability of a case study implies demonstrating that the operations of a study (such as the data collection procedures) can be repeated, with the same results (Yin 1981).

6 Not all authors agree on this issue. Kathleen Eisenhardt, for instance, argues that case studies that aim to build theories should attempt to approach the ideal of entering the case with a clean theoretical slate, because preordained theoretical perspectives or propositions may bias and limit the findings. (Eisenhardt 1989, p. 536)

2 Towards a framework

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2.1 Introduction

Awareness has risen among scholars and policy makers that fundamental changes are necessary in energy supply, agriculture, water management and many other sectors in order to reach a sustainable future (Rotmans 2003; Van Lente, Smits et al. 2003). The terms 'socio-technological transformation', 'system innovations' and 'transition' have been used to describe these fundamental transformation processes. Socio-technological transformation (STT), as we will call it in this article, is defined as a major, long-term technological change in the way societal functions (such as the supply of energy) are fulfilled (Geels and Kemp 2000; Geels 2002a). This long-term transformation at the level of society as a whole, in turn consists of a sequence of short-term innovations (Geels 2002a; Geels 2002b). Transformations like these take at least one generation and involve mutually reinforcing developments in different domains of society, such as economy, technology and politics (Rotmans, Kemp et al. 2000).

Several authors have argued that STTs are difficult to achieve because the prevailing socio-technological system acts as a barrier to the creation of a new socio-technological system (e.g. (Kemp and Soete 1992; Freeman and Perez 1998; Grubler, Nakicenovic et al. 1999b; Jacobsson and Johnson 2000; Unruh 2000; Geels 2002a)). Established socio-technological systems often benefit from increasing returns to adoption. This means that technologies become more attractive when they are adopted more widely (Arthur 1988). Important causes of increasing returns to adoption are learning by using, network externalities, scale economies in production, informational increasing returns and technological interrelatedness (Arthur 1988). These increasing returns to adoption lead to path-dependency and irreversibility. The socio-institutional framework is aligned to the existing technology by a process of technological and institutional co-evolution. This can lead to a lock-in of the prevailing system: the prevailing system has gained an advantage on the basis of its history, not on the basis of technical superiority (Van Lente, Smits et al. 2003). This lock-in situation makes it difficult for new technologies to break through.

One can conclude from these studies that STT is a highly complex process, which involves many uncertainties. These uncertainties play a key role since they are considered to be one of the major blocking mechanisms of STTs (Kemp, Schot et al. 1998; Jacobsson and Johnson 2000; Rotmans 2003). First, the direction and speed of STTs are highly uncertain due to the large number of possible options. There are several visions about the final objective of the STT, and these visions constantly change during the transformation process to adapt to new situations (Rotmans, Kemp et al. 2001). This results in an infinite number of possible future outcomes. In addition, several paths (or 'technological trajectories') are possible to reach each of these outcomes. In turn, each technological trajectory can be composed of several configurations of more or less radical[1] short-term innovations, namely the innovation decisions[2] of individual actors (also called 'transition steps') (Suurs, Hekkert et al. 2004). Second, each of the individual innovation decisions is itself surrounded by uncertainties (e.g. Nelson and Winter 1977; Dosi 1982; Freeman, Clark et al. 1982; Edquist 1997; Smits and Kuhlmann 2004). The uncertainties that the actors involved perceive greatly influence their decisions and behaviour and can prevent the actor from participating in the transition step. Since the behaviour of individual actors collectively determines the speed and direction of STT, these perceived uncertainties are likely to hinder the transformation as a whole.

Several standard responses to uncertainty can be distinguished. One of these responses is to delay or even to abandon innovation decisions. Since we focus on innovations that contribute to sustainability, this is undesirable. Another standard response is to ignore the uncertainty, with the risk of making false decisions based on imperfect information. As a result, an innovation is rejected falsely (based on wrong or incomplete information) or adopted falsely (choosing a sub-optimal alternative because information about other alternatives is lacking). A response that does acknowledge uncertainty is collecting information in order to reduce uncertainty. However, new information can uncover uncertainties that were previously unknown (Van Asselt 2000). Furthermore, uncertainty often arises because information can be interpreted differently (Koppenjan and Klijn 2004). Collecting information or conducting research often only strengthens this difference in opinions. Thus we conclude that those standard responses to uncertainty frequently appear to have a negative effect on innovation and STT. In order to stimulate the STT towards a sustainable future, management strategies and policy instruments are needed that are more adequate in coping with uncertainty than the standard responses described above. Therefore, a thorough understanding of the uncertainties that underlie the behaviour of actors is a prerequisite.

The importance of uncertainty in decision-making processes in general seems widely recognized. Psychological decision theorists have provided useful insights into the influence of uncertainty on decision-making (e.g. Tversky and Kahneman 1974; Vlek and Stallen 1980), and strategic management and organizational theorists have shown that uncertainty is a key factor influencing strategic management and organizational decision-making (e.g. Porter 1980; March 1988; March and Shapira 1988). Thompson (1967) even stated that the principal challenge facing an organization is coping with uncertainties. In addition, innovation theorists seem well aware of the intrinsically uncertain character of innovation processes (including STT) (e.g. Nelson and Winter 1977; Dosi 1982; Freeman, Clark et al. 1982; Edquist 1997). Smits and Kuhlmann (2004) even speak of a trend of increasing uncertainty in the interrelated development of innovation practice, theory and policy. However, some authors argue that, despite the fact that many authors stress the importance of uncertainty in innovation, the concept of uncertainty is poorly elaborated in innovation studies (Fleming 2001; Corral 2002). From innovation studies we have not learned yet whether and how perceptions of uncertainties differ between the sequential phases of the transformation process and between types of actors. The aim of this article is to come to a better understanding of the role of uncertainties in STT by addressing the following research question:

What framework is relevant for studying the role of uncertainties in socio-technological transformation (STT)?

To answer this research question, we first discuss the literature on STT and discuss which types of actors are involved and which phases are generally discerned in literature. Then we review the uncertainty and innovation literature to come to a typology of uncertainties. Finally we complete the framework by linking the uncertainty typology to the different phases of STT and actors involved, and discuss the implications for policy.

2.2 Socio-technological transformation (STT)

STT can be studied at different aggregation levels. We make a distinction between the level of individual actors and the level of the system. The behaviour of individual actors greatly influences the direction and speed of STT. Therefore, it is important to gain insight into the uncertainties that influence the innovation decision at the level of individual actors. However, to manage STT it is impossible to steer at this individual level. Due to the large number of different actors involved in STT and the interdependencies between these actors, none of the actors can steer STT on their own. In order to steer STT, a system-level perspective is needed. An 'innovation system'-approach seems appropriate, since this approach analyzes interaction between the parties involved in innovation and the resulting collective performance (Van Lente, Smits et al. 2003). Central to this approach is the idea that organizations are not innovating in isolation but in the context of a system (Freeman and Lundvall 1988; Nelson 1988; Lundvall 1992; Barré, Gibbons et al. 1997; Smits and Kuhlmann 2004).

The innovation system can be described by distinguishing the following subsystems and mutual relations (see Figure 2-1), (Smits 1994; Van Lente, Smits et al. 2003):

- supply: production of knowledge and technology
- demand: intermediate and final demand of technology and knowledge
- intermediaries: organizations, institutions and instruments aimed at improving the interface and exchange of knowledge between the various parties
- supportive infrastructure: comprising material and immaterial infrastructures, such as banking, standards and legislation.

One of the consequences of the growing influence of innovation systems on the innovation process of individual organizations is that the performance of organizations is dependent on the quality of the innovation system, it's subsystems (depicted in Figure 2-1) and, maybe even more, on the mutual tuning of these subsystems (Freeman 1997; Smits 2002). Besides, more and very heterogeneous actors, often at very different levels and operating in various arenas, are involved in the innovation process. Since the mid-eighties, innovation systems have developed from systems with discrete, loosely coupled entities into systems with strongly interlinked entities with

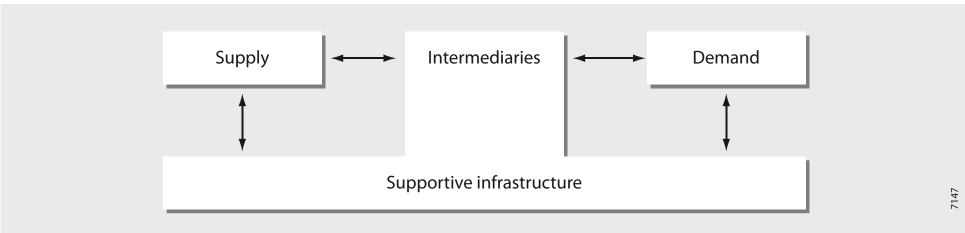

Figure 2-1 The innovation system (Smits 1994).

rather fuzzy boundaries. More and more, innovation, and even decision making in general, has become a network activity (Koppenjan and Klijn 2004; Smits and Kuhlmann 2004).

With respect to uncertainties, it becomes clear that the growing influence of innovation systems on the innovation decisions of organizations adds to the uncertain character of innovation and STT. As a result, in order to understand uncertainties regarding STT it is important to study uncertainties of STT at both the level of the individual actors and at the level of the innovation system. We shortly discuss the implications of these two levels with respect to policy and management of uncertainties in the final section.

2.2.1 The actors

Since perceptions of uncertainty will likely vary between different types of actors involved in STTs, we briefly describe a classification of actors.[3] We first make a distinction between private actors, public actors and NGOs (non-governmental organizations) since these actors have different backgrounds, goals and means and thus will likely have different perceptions of uncertainties and strategies to cope with these uncertainties. Secondly, we categorize the actors according to their position in the innovation system, e.g. according to the subsystem to which they belong (see Figure 2-1). Finally, we distinguish between the roles that actors play, such as producing knowledge or making policy. It is important to note that actors can play several roles and thus occupy multiple positions in the innovation system, either in different phases of the STT or simultaneously. A well-known example of an actor that occupies several roles is the government, whose roles are launching customer (demand-side), regulator (supportive infrastructure), guardian of the infrastructure (supportive infrastructure) and facilitator (intermediary). Another example is an industrial firm, who simultaneously is a buyer of knowledge (demand-side of the innovation system) and a supplier of a technological product (supply-side of the innovation system), depending on which value-added chain and which element of this chain is focused on. The categorization of actors is illustrated in Table 2-1, where the cells depict some of the roles that the actor can fulfil.

Table 2-1 Categorization of actors.

Actor	Position			
	Supply	**Demand**	**Intermediary Infrastructure**	**Supportive Infrastructure**
Public actor e.g.: government,		launching customer	facilitator	regulator, guardian of the infrastructure
university	producer of knowledge			
Private actor e.g.: industrial firms, consulting firms, households	producer of technology, producer of knowledge	user of technology, user of knowledge	interface between supply and demand	
NGO e.g.: environmental or consumer organizations			facilitator/broker between supply, demand and policy	

2.2.2 The phases

Besides describing the innovation system according to its structural characteristics (see Figure 2-1), we can look at the functioning and dynamics of innovation systems. In this way, we can describe STT in terms of innovation system change.

Based on the evolutionary approaches to innovation which describe technical change according to the analogy of life cycles (e.g. Nelson and Winter 1977; Tushman and Rosenkopf 1992; Utterback 1994), STTs or the underlying technological trajectories can be simplified and divided into four phases (see Figure 2-2) (Rotmans, Kemp et al. 2001; Van Lente, Smits et al. 2003):

1. exploration or pre-development phase
2. take-off phase
3. acceleration or entrenchment phase
4. stabilization phase.

Figure 2-2 offers a graphical representation of the typical S-curve that is associated with the process of STT. This S-curve finds its origin in the technology S-curve by Foster (1986), which depicts the growth of technology performance over time, and in the diffusion curve of Rogers (1995) where the vertical axis depicts the diffusion of innovations. In the case of STT, the vertical axis depicts system change, which combines technology diffusion and the growth of the innovation system. In the sustainable development literature, system change is synonymous with sustainable development (Rotmans, Kemp et al. 2001; Rotmans 2003).

Although the sequential character of the phase-model appears to deny the iterative, multi-linear process of innovation, we think that analyzing STT in terms of phases can be useful provided that we are aware of the simplifications of this model (Van Lente, Smits et al. 2003). The description of the phases below is derived from previous work (Van Lente, Smits et al. 2003).

Pre-development phase

In the pre-development or exploration phase (number 1 in Figure 2-2), new options and varieties emerge, together with the awareness that new directions are needed. There is a multitude of

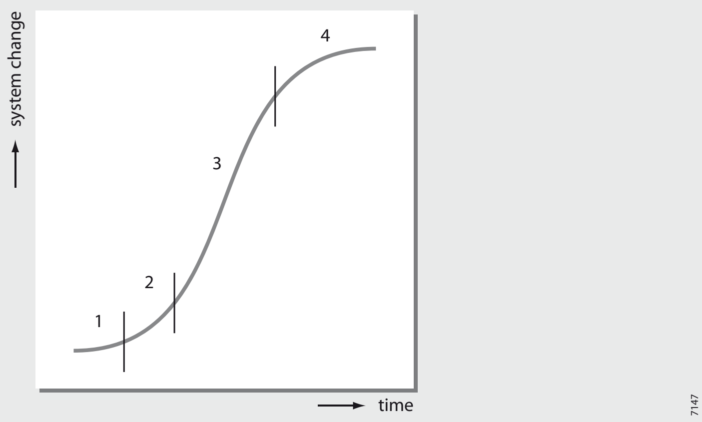

Figure 2-2 S-curve of socio-technological transformation (adapted from Foster 1986).

search processes in which various routes and options are suggested and tried (non-linearity). A key characteristic of this phase is the combination of, on the one hand, eagerness to find out what is possible, and, on the other hand, resistance to change existing configurations. This relates to the Schumpeterian notion of 'creative destruction': an innovation provides new possibilities for industries, users and stakeholders while simultaneously transforming or destroying prior vested interests. A second characteristic of the search processes is the interrelatedness of innovations. New technologies refer to and build on older inventions. In addition, technical changes co-evolve with social changes.

Take-off phase

When new possibilities have been defined and explored and new futures have been expressed, a competition between trajectories can be expected. This occurs in the take-off phase (number 2 in Figure 2-2). This is comparable to the metaphor of life cycles of innovation that describe how new technologies compete with both established technologies and other new technologies until a dominant design emerges (e.g. Tushman and Rosenkopf 1992; Utterback 1994). In the case of STT, more is at stake than the succession of technologies; it is rather a change of the whole system. System changes often involve a change in *technological paradigms*, namely changes in the established set of procedures, the definition of problems that are considered relevant and the strategies to solve them (Dosi 1982).

Competition between the old and the new system is frequently hampered by the occurrence of a lock-in situation (Arthur 1988). Due to increasing returns to adoption, the established system has gained an advantage on the basis of its history, which makes it difficult for new technologies to break through. A way to expedite the introduction of new technologies is to introduce them in a protected space or niche (Kemp, Schot et al. 1998).

In the competition between the established and the emerging system, expectations play a crucial role. Due to the interconnectedness and learning curves of technologies, it is important to avoid taking a direction that is not followed by others or to miss jumping on the 'bandwagon'. In deciding which route to take, stakeholders will take account of what others will do, or, better, what they expect what others will do (Van Lente 1993). Thus, perceptions of the (future) behaviour of others are an important factor in shaping the overall direction of technological change.

Acceleration phase

In the acceleration phase, also known as the entrenchment or embedding phase (number 3 in Figure 2-2), the various socio-technological developments of a new system have become interconnected and reinforce each other. The system may become irreversible: the developments have become so intertwined that the system has a life of its own, as it were. Thomas Hughes described this with the term 'momentum' (Hughes 1983). In this phase, it is important that stakeholders succeed to profit from experiences and interactions (learning by doing). Typical for this phase is the shake out that takes place regarding the number of technology producers (Utterback 1994).

Stabilization phase

In the stabilization phase (number 4 in Figure 2-2), the new system has become so entrenched in current routines, infrastructure and legal frameworks that it has become an established, robust system itself and can only with considerable costs and effort be undone. Most changes will be incremental and build on economies of scale. The system can become unstable when a new technological system arises that starts to take over. As a result, a new life cycle starts and the role of uncertainties increases again.

2.3 What is uncertainty?

Having described STT, we now turn to the main issue of this paper, namely uncertainty. Reviewing the literature on uncertainty, it becomes clear that although much research has dealt with the conceptualization of uncertainty, there is a lack of consensus about the definition, classification and operationalization of uncertainty (Duncan 1972; Gifford, Bobbitt et al. 1979; Jauch and Kraft 1986; Sutcliffe and Zaheer 1998; Kreiser and Marino 2002; Van Geenhuizen and Thissen 2002; Walker, Harremoes et al. 2003).

In this article, the term 'uncertainty' will be defined broadly as "*any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system*" (Walker, Harremoes et al. 2003, p. 5). It is important to note that gathering information cannot always reduce uncertainty. Uncertainty can exist even in situations where much information is available (Van Asselt 2000; Koppenjan and Klijn 2004). In our terminology, uncertainty also relates to aspects that are by definition indeterminable, such as the behaviour of other actors (March 1988; Koppenjan and Klijn 2004).[4] Often the underlying factors that determine the behaviour of other actors (such as their interests, objectives, procedures, etc.) are uncertain to other actors. Furthermore, behaviour constantly changes, while actors react to and anticipate each other's behaviour and unexpected events. (Koppenjan and Klijn 2004)

A continuing debate among scholars of uncertainty is the discussion about objective versus perceived uncertainty (e.g. Jauch and Kraft 1986; Kreiser and Marino 2002). Supporters of the objective view on uncertainty define uncertainty as a characteristic of the environment that can be measured objectively (Dess and Beard 1984). Supporters of the perceptive view on uncertainty argue that uncertainty is dependent on the individual and cannot be measured objectively (Milliken 1987). The term 'perception' refers to the process by which individuals organize and evaluate stimuli from the environment. What is certain to one actor, does not have to be certain to another (Huff 1978). The existence of information itself lacks meaning until an individual perceives it (Corrêa 1994). Environments are therefore neither certain nor uncertain but are simply perceived differently by different actors. In this article, we look at uncertainties as a determinant of innovation behaviour of actors. Since perceptions of uncertainty can be seen as one of the driving forces of actor behaviour, this article focuses on 'perceived uncertainty' (as opposed to 'objective uncertainty'). In the remainder of this article, 'uncertainty' refers to 'perceived uncertainty'.

2.3.1 Classifying uncertainty

Having defined the concept 'perceived uncertainty', we can now introduce a typology of uncertainties. In doing so we will classify perceived uncertainties according to their nature, level and source (adapted from Walker, Harremoes et al. 2003). The source of uncertainty can be seen as the first order classification (the 'variables') and the nature and level of uncertainty as the second order classification (the 'dimensions' that constitute the variable) (see Table 2-2).

Nature of uncertainty

In the previous section, we defined uncertainty as "*any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system*" (Walker, Harremoes et al. 2003, p. 5), which not only relates to a lack of information, but also to aspects that are indeterminable (such as the behaviour of other actors). We choose for this broad definition to include not only those uncertainties that could be reduced by knowledge creation, but also to include uncertainty that is indeterminable and therefore cannot be reduced by knowledge creation. This brings us to a characterization of uncertainty on the highest level of aggregation, what Walker et al. (2003) describe as the *nature* of uncertainty. However diverse the literature on uncertainty may be, at this level of aggregation there seems to be consensus about two types of uncertainty (Gifford, Bobbitt et al. 1979), which can be described as follows (Boyd and Fulk 1996; Van Asselt 2000; Walker, Harremoes et al. 2003):[5]

- **knowledge uncertainty**: Uncertainty that is a property of the decision maker and of the human stock of knowledge. Knowledge uncertainty can be caused by a *lack of information* (Van Asselt 2000)[6] or by *complexity* (large number of elements and high level of interdependence among those elements) (Boyd and Fulk 1996). This type of uncertainty can in principal be reduced by knowledge creation and learning.
  Other terminologies used for knowledge uncertainty are weak, internal, secondary, substantive, or epistemic uncertainty (Koopmans 1957; Kahneman, Slovic et al. 1982; Jauch and Kraft 1986; Williamson 1987; Dosi and Egidi 1991; Helton 1994; Van der Sluijs 1997; Van Asselt 2000; Rammel and Bergh 2003; Walker, Harremoes et al. 2003).
- **variability uncertainty:** Uncertainty that is inherent to the variability of the system (changes of the environment) and therefore cannot be reduced (Walker, Harremoes et al. 2003). Changes in the environment can create a large number of potential outcomes, thus decreasing confidence in predictions (Boyd and Fulk 1996). It is an attribute of reality. For example: uncertainty due to the inherent randomness of nature, human behaviour, social/economic/cultural dynamics, technological surprise, and so on.
  Other terminologies for variability uncertainty are strong, fundamental, stochastic, random, primary, external, procedural, ontological or aleatory uncertainty (Koopmans 1957; Kahneman, Slovic et al. 1982; Jauch and Kraft 1986; Van Witteloostuijn 1986; Dosi and Egidi 1991; Helton 1994; Van der Sluijs 1997; Van Asselt 2000; Rammel and Bergh 2003; Walker, Harremoes et al. 2003).

Since gaining knowledge might help to overcome knowledge uncertainty, but is unsuitable for handling variability uncertainty, it is important for managers or policy-makers to determine the nature of uncertainty.

Level of uncertainty

The level of uncertainty relates to *how* uncertain the situation is. The level of uncertainty can be seen as a spectrum, running from complete deterministic understanding to total ignorance (Van Asselt 2000; Walker, Harremoes et al. 2003). A high level of uncertainty calls for different strategies than a low level of uncertainty (Courtney, Kirkland et al. 1997; Van Asselt 2000; Walker, Harremoes et al. 2003). In very uncertain situations, traditional forecasting strategies are inappropriate, and it is even more important than in situations with low uncertainty to apply a robust strategy (which will work in a variety of situations) or an adaptive strategy (which can be easily modified to fit the situations encountered) (Walker, Harremoes et al. 2003).

Source of uncertainty

The source of uncertainty is the domain of the organizational environment which the decision-maker is uncertain about (Milliken 1987). Distinguishing between different sources of uncertainty is important for choosing appropriate strategies to cope with the uncertainty (Wernerfelt and Karnani 1987).

What is seen as a source of uncertainty strongly depends on the context. In this article we focus on uncertainties in organizational decision-making regarding innovation projects. Two bodies of literature are therefore important to review in order to identify often-mentioned sources of uncertainty, namely the management and organizational literature and the innovation studies literature. The management and organizational literature on uncertainty have theorized that various elements of the environment, such as customers, competitors and governmental regulation, act to create uncertainty for firms (e.g. Thompson 1967; Duncan 1972; Porter 1980; Milliken 1987; Kreiser and Marino 2002). Although this body of literature provides a useful overview of elements that influence organizational decision-making, it does not focus on innovation decisions. Therefore, we proceed in our literature review with the innovation literature on uncertainty. We notice that the innovation studies that make a distinction between sources of uncertainty, seem to focus on either the adoption of innovations (e.g. Sommers 1980; Mamer and McCardle 1987; Gerwin 1988; Nooteboom 1989; Farzin, Huisman et al. 1998; Marra, Pannell et al. 2003) or on the development of innovations (e.g. Moenaert and Souder 1990; Mullins and Sutherland 1998; Magnusson and Berggren 2001; Buyukozkan and Feyzioglu 2004; Chesbrough 2004). Since STT involves decisions of actors both to develop and to adopt innovations, we make a classification of uncertainty sources that relates to both types of innovation decisions. We have made a list of sources that are mainly discussed in the organizational management and innovation studies literature, namely:[7]

- **technological uncertainty**: e.g. (Thompson 1967; Duncan 1972; Porter 1980; Mamer and McCardle 1987; Gerwin 1988; Moenaert and Souder 1990; Shenhar, Dvir et al. 1995; Farzin, Huisman et al. 1998; Mullins and Sutherland 1998; Souder, Sherman et al. 1998; Jennings and Jones 1999; St John, Pouder et al. 2003; Buyukozkan and Feyzioglu 2004; Carlsson and Jacobsson 2004; Chesbrough 2004; Foxon, Gross et al. 2005)
- **resource uncertainty** (including uncertainty regarding labour and capital markets): e.g. (Duncan 1972; Pfeffer and Salancik 1978; Moenaert and Souder 1990; Miller 1993; Farzin, Huisman et al. 1998; Mullins and Sutherland 1998; Jennings and Jones 1999; St John, Pouder et al. 2003)
- **competitive uncertainty**: e.g. (Duncan 1972; Pfeffer and Salancik 1978; Porter 1980; Mamer and McCardle 1987; Milliken 1987; Moenaert and Souder 1990; Miller 1993; Farzin, Huisman et al. 1998; Jennings and Jones 1999; St John, Pouder et al. 2003)
- **supplier uncertainty** e.g. (Duncan 1972; Porter 1980; Milliken 1987; Miller 1993; Jennings and Jones 1999; St John, Pouder et al. 2003; Buyukozkan and Feyzioglu 2004)
- **consumer uncertainty**: (also known as market uncertainty) e.g. (Duncan 1972; Porter 1980; Milliken 1987; Moenaert and Souder 1990; Miller 1993; Farzin, Huisman et al. 1998; Mullins and Sutherland 1998; Souder, Sherman et al. 1998; Jennings and Jones 1999; St John, Pouder et al. 2003; Buyukozkan and Feyzioglu 2004; Carlsson and Jacobsson 2004; Chesbrough 2004; Foxon, Gross et al. 2005)
- **political uncertainty** (also called regulatory uncertainty or policy uncertainty): e.g. (Thompson 1967; Duncan 1972; Marcus 1981; Rothwell and Zegveld 1981; Birnbaum 1984; Milliken 1987; Miller 1993; Jennings and Jones 1999; Carlsson and Jacobsson 2004; Foxon, Gross et al. 2005)

Below, each of the sources is described in more detail.

Technological uncertainty
Perceived uncertainty about the technology can relate to the technology itself, to the relation between the technology and the technological system or to the availability of alternative technological solutions (both technologies that are already available and technologies that might become available in the future).

- *Uncertainty about the technology itself*

The decision to invest in an innovation is influenced by the decision maker‘s perception of the technology itself. A large body of literature exists that focuses on characteristics of innovations that influence the innovation decision (e.g. Ostlund 1974; Tornatzky and Klein 1982; Rogers 1995), such as the relative advantage (in terms of cost-reduction, higher efficiency, etc.) of an innovation compared to the technology currently in use (Rogers 1995). The decision maker's perception of the innovation characteristics determines whether a firm will invest in the new technology. However, when a new innovation emerges, information about the innovation (especially information based on experience with the technology) is limited. In addition, the characteristics of the innovation keep changing while further improvements are being made. As a result, decision makers will have difficulty in evaluating the innovation characteristics (Gerwin 1988). This technological uncertainty will hinder a proper evaluation of the innovation and thereby complicate the innovation decision. The more complex or radical a technology is[8], the higher the technological uncertainty will be (Tushman and Rosenkopf 1992; Rogers 1995). Since incremental innovations constitute relatively minor changes, it will be easier for decision makers to forecast the performance of the innovation in terms of the perceived innovation characteristics than will be the case for radical innovations. An example that illustrates the influence of uncertainty about the characteristics of a technology on the innovation decision can be found in a study on nuclear power plants (Sommers 1980), where uncertainty about the capital cost and the reliability of nuclear power plants relative to state-of-the-art coal-fired plants is mentioned as an important barrier affecting the adoption decision.[9]

- *The relation between the technology and the technological infrastructure*

Technological uncertainties can also arise about the relation between the technology and the technological infrastructure in which the technology is embedded. Change of either the technology or the infrastructure can influence the relation between the two. On the one hand, uncertainty can arise about the effect of introducing a new technology in the technological infrastructure. In other words, this technological uncertainty relates to if and to what extent adaptations need to be made to the technological infrastructure in order to connect a new technology to the infrastructure. Some new technologies only need small adaptations to the existing infrastructure, while others require large adaptations to the existing infrastructure or even the emergence of an entirely new infrastructure. The latter can be the case for radical, disruptive technologies. However, the establishment of entirely new infrastructures is extremely difficult to conceptualize beforehand (Rosenberg 1996). Since infrastructures require large investments and have long life spans, adaptations to the infrastructure are difficult to implement. Uncertainty about the extent to which adaptations need to be made to the infrastructure will therefore influence the decision to develop or adopt a new technology. On the other hand, uncertainty can arise about future changes in the infrastructure and the effect of these changes to existing technologies. The emergence of a new infrastructure could cause that adaptations have to be made to current technologies or that current technologies become obsolete. Organizations will hesitate to invest in technologies that require a new infrastructure or, vice versa, to invest in a new infrastructure when technologies that require that new infrastructure are still absent. For example, uncertainty about the emergence of a hydrogen infrastructure is seen as one of the major barriers to large-scale application of hydrogen technologies such as fuel cell vehicles (Ogden, Steinbugler et al. 1999; Foxon, Gross et al. 2005).

- *The possibility of choosing alternative technological options*

Another cause of technological uncertainty is the possibility of choosing alternative technological options.[10] In most situations, actors can choose between several competing technologies. Competition exists between old and new technological regimes, but also within new technological regimes (Tushman and Rosenkopf 1992). In other words, actors not only compare a new technology with the existing technology, but also with other new technologies that are available at that moment. The uncertainty with respect to multiple alternatives increases even more when one takes into account the possibility that actors can decide to wait for the arrival of a new generation of technologies. The ongoing process of technological change creates uncertainty with respect to the technological learning curve of technologies (Gritsevskyi and Nakicenovi 2000), the speed of the arrival of new technologies (Farzin, Huisman et al. 1998), the degree of improvement of new technologies relative to current state-of-the-art technologies (Farzin, Huisman et al. 1998), as well as uncertainty about the possibility that future technologies can cause older technologies to become obsolete (Gerwin 1988). If the process of technological change is rapid, firms have little time to regain their investments. Firms face a problem of having to choose between the cost of making a mistake by adopting too soon (sunk cost, problem of irreversibility) or, on the contrary, the opportunity costs of adopting too late (Dixit and Pindyck 1994; Farzin, Huisman et al. 1998; Doraszelski 2004).

Resource uncertainty

Resource uncertainty can be described as perceived uncertainty about the availability of raw material, human and financial resources needed for innovation (e.g. Moenaert and Souder 1990; Farzin, Huisman et al. 1998). Resource uncertainty is caused by the difficulty of making accurate forecasts of the resources that are needed for innovation projects. In addition, actors may perceive uncertainty about the availability of the required resources and about how to organize the innovation process (in-house or external R&D, technology transfer, educating personnel, and so on).

Uncertainty about the allocation of financial resources relates to the uncertainty of how much capital to invest in the innovation project (Mullins and Sutherland 1998), as well as whether the firm can finance the project internally or should obtain external funding.

Uncertainty regarding human resources relates to the availability of knowledge and skills needed to carry out the innovation project. In the first place, uncertainty can exist about the firm-internal allocation of human resources. Does the firm have sufficient capacity of skilled employees? If there is a lack of human resources at the firm-internal level, the external availability of resources (namely the innovation system level) becomes important. Thus, secondly, uncertainty can arise about the ability of firms to acquire human resources from the innovation system. The availability of resources at the innovation system is dependent on the educational system and the labour market. Firms have several possibilities for obtaining knowledge, such as educating current employees, engaging new employees or collaborating with research institutes, universities and other organizations (Tidd, Bessant et al. 2001).

Assumably, resource uncertainty will be higher for producers than for users of a new technology because the development of new technologies requires that people have the skills and know-how to go further than current practice. Furthermore, resource uncertainty will be higher for radical than for incremental innovations.[11] Radical, competence-destroying discontinuities build on a new knowledge base. Therefore, the more radical an innovation, the more adaptations have to be made in resources (Anderson and Tushman 1986).

Competitive uncertainty

Perceived uncertainty about the actions of (potential or actual) competitors[12] (e.g. Mamer and McCardle 1987; Moenaert and Souder 1990) can either be innocent (arising from a lack of awareness about the prospective actions of competitors) or 'strategic' (when firms deliberately create uncertainty for their competitors in order to gain a strategic advantage) (Sutcliffe and Zaheer 1998). There is not only uncertainty about which strategies competing actors will use, but also about the *effects* of these strategies on the competitive position of the firm. Among the major factors that influence the competitive game are the existence of 'first mover advantages', economies of scale and the number of competitors (Wernerfelt and Karnani 1987).[13]

The categorization of actors given above (see Table 2-1) is especially important with respect to competitive uncertainty because the role of an actor determines which firms or institutions are viewed as competitors. For example, technology producers who compete with each other for customers can perceive uncertainty about when the competitor will bring his competing technology to the market and which marketing strategies he will use. The uncertainty perception of technology users and adopters is different. In this case competitive uncertainty can arise about the adoption behaviour of competitors, e.g. can a competitor gain strategic advantage by adopting the technology first?

Supplier uncertainty

Another source of perceived uncertainty is uncertainty about the actions of suppliers (e.g. Buyukozkan and Feyzioglu 2004). Uncertainty about the actions of suppliers amounts to uncertainty about the timing, the quality and the price of the delivery (Hedaa 1993; Kouvelis and Milner 2002). Again, the categorization of actors given above (see Table 2-1) is important to determine which firms are viewed as supplier. Supplier uncertainty includes uncertainty about partners in a joint venture. As long as there are still organizational boundaries between partnering firms, partners are comparable to external suppliers since partners also supply each other with capital, goods or knowledge.[14]

When the dependence on a supplier is high, supplier uncertainty becomes increasingly important. In this case, suppliers have more bargaining power and can create uncertainty about their actions by threatening to lower the quality or increase the prices of their products. Several factors influence the dependency on a supplier, such as the number of suppliers, the presence of substitute products, the size of the transaction costs (costs of switching from one supplier to another), or the threat of forward integration by suppliers (Porter 1980).

Furthermore, supplier uncertainty is also influenced by past experiences with the supplier. Positive experience reduces perceived uncertainty in the relationship. Trust gradually builds up over time, based on accumulated positive experience. For innovations that require the establishment of new relations with suppliers, uncertainty will likely be higher than for innovations that build on the existing relations with suppliers. Therefore, one of the reasons for establishing long lasting relationships is to reduce uncertainty (Hedaa 1993).[15]

Consumer uncertainty
The decision of an organization to invest in a new technology is highly influenced by perceived uncertainty about their consumers. Without a market for the new technology, organizations will not invest in the development or distribution of the technology.

• *Uncertainty about consumer preferences*
One the one hand, uncertainty can arise about consumers' preferences with respect to the new technological innovation. Consumer preferences will determine whether or not the consumer will adopt the innovation. In the case of innovations, consumers' expectations regarding product characteristics, quality, prices, appropriate distribution channels and so on are uncertain (Wernerfelt and Karnani 1987; Moenaert and Souder 1990; St John, Pouder et al. 2003). Potential customers cannot easily articulate their needs and preferences that the new technology should fulfil (Mullins and Sutherland 1998). As a result, technology producers perceive uncertainty about the market opportunities of the new technology.

• *Uncertainty about the consumer characteristics*
Besides uncertainty about consumer preferences, uncertainty can arise with respect to the characteristics of consumers. A prerequisite for successful innovation is the technology's compatibility with the consumer characteristics. Technology developers need certainty about consumer characteristics in order to develop a useful innovation. For example, an important consumer characteristic with respect to energy technologies is the size of the energy demand. These consumer characteristics, together with consumer preferences, are needed to decide along which dimensions to segment the market (Wernerfelt and Karnani 1987).

• *Uncertainty about the development of the demand*
The above causes of consumer uncertainty together with some macro-economic developments (such as population growth, which enlarges the potential market size, or the state of trade, which influences the purchasing power of potential consumers) cause uncertainty about the development of the demand over time. Uncertainty about the development of the demand consists of uncertainty about the size of the demand and when the demand will stabilize.

Political uncertainty
Political uncertainty (also known as regulatory uncertainty or governmental uncertainty) stems from perceived uncertainty about governmental behaviour, regimes and policies. Political uncertainty can affect the rate, timing and substance of an innovation (Marcus 1981). Political uncertainty can have several causes:

- *Current policy*

Current policy, including education or economic policy, is an important factor influencing innovation decisions. The effect of current policy can be uncertain, for example due to changes in external factors (e.g. recession, ageing of the population) (Carlsson and Jacobsson 2004).

- *Unclear or inconsistent regulation*

Uncertainty about current governmental regulation can exist due to unclear regulations (ambiguity about the interpretation of laws) or inconsistencies (e.g. contradictions between local and national government) (Rothwell and Zegveld 1981).

- *Lack of regulation*

It is also possible that political uncertainty arises from a lack of regulation. New developments (such as radical technological breakthroughs) can call for new regulation. For example, the emergence of ICT (information communication technology) caused the establishment of new privacy legislation.

- *Future changes*

Another cause of political uncertainty arises from future changes in regulation and legislation (Rothwell and Zegveld 1981; Foxon, Gross et al. 2005). This uncertainty is increased if the changes occur very rapidly and are hard to predict. Regulatory changes that create uncertainty for decision makers can arise from both new legislation and unpredictable changes in current regulations (Carter 1990).

- *Governmental behaviour*

Finally, political uncertainty arises from a general climate of uncertainty, as Rothwell and Zegveld (1981) describe it. We interpret this as uncertainty about the behaviour of the government. One of the causes of this uncertainty is when governmental spokespersons say different things than they eventually do.[16] For example, receiving subsidy for the investment in a new technology will have a positive influence on the cost-benefit analysis that underlies the investment decision. Uncertainty with respect to actually receiving the subsidy can lead to delay or even rejection of the plans to invest in new technologies. Furthermore, other parties (such as the media, environmental organizations or trade unions) can influence the political debate and the image other parties have of the government. Stakeholders can call into question the effectiveness and desirability of policy plans and thereby contribute to the creation of a general climate of uncertainty. As we mentioned above with respect to supplier uncertainty, uncertainty about governmental behaviour is closely related to trust and credibility.

The typology of perceived uncertainties that has been described in the previous section is summarized in Table 2-2.

2.4 Relating uncertainties to STT

To use the uncertainty typology in innovation system policy successfully, it is necessary to acknowledge the fact that different types of uncertainty will dominate in different phases of STT. We relate the uncertainty typology to the phase-model of STT in a coherent framework (see Table 2-3) that can be applied to analyze the role of uncertainties in STT in empirical cases.[17] The dominancy[18] of the uncertainty sources can be ranked in each phase, on an ascending scale from 0 via + to ++. A new table should be used for each of the actors in order to analyze whether and how perceptions of uncertainty differ for different types of actors. In Table 2-3, we give an example of how the pattern of dominant perceived uncertainties in different phases might look, based on general insights from innovation studies. In this example, we have chosen the perspective of technology developers.

We expect that technology developers will perceive technological uncertainty as most dominant in the pre-development phase and gradually decreasing in the subsequent phases, when the technology has proven itself on the market (Anderson and Tushman 1990; Tushman and Rosenkopf 1992; Afuah and Utterback 1997; St John, Pouder et al. 2003; Carlsson and Jacobsson 2004). In the pre-development phase, uncertainty about what is possible and which direction to choose is very high. In the take-off phase, it is still unclear which technology will dominate on

Table 2-2 Typology of perceived uncertainties.

Variable		Dimension	Scale
Technological uncertainty	e.g.: • uncertainty about the technology itself • uncertainty about the relation between the technology and the technological infrastructure • uncertainty about the availability of alternative technological solutions	Nature Level	Knowledge vs. variability Low[a] … High[b]
Resource uncertainty	e.g.: • uncertainty about the amount and the availability of financial resources • uncertainty about the amount and the availability of human resources	Nature Level	Knowledge vs. variability Low[a] … High[b]
Competitive uncertainty	e.g.: • uncertainty about the actions of (potential or actual) competitors • uncertainty about the effects of competitors' actions	Nature Level	Knowledge vs. variability Low[a] … High[b]
Supplier uncertainty	e.g.: • uncertainty about the timing, quality and price of the delivery	Nature Level	Knowledge vs. variability Low[a] … High[b]
Consumer uncertainty	e.g.: • uncertainty about consumers' preferences • uncertainty about consumers' characteristics • uncertainty about the development of the demand	Nature Level	Knowledge vs. variability Low[a] … High[b]
Political uncertainty	e.g.: • unclear or inconsistent regulation • lack of regulation • future changes in regulation • governmental behaviour	Nature Level	Knowledge vs. variability Low[a] … High[b]

a. Low = complete determinism
b. High = complete ignorance

Table 2-3 Framework for analyzing patterns of dominant perceived uncertainties: the example of technology developers.

Sources	Phases			
	Pre-development	Take-off	Acceleration	Stabilization
Technological uncertainty	++	+	0	0
Resource uncertainty				
• financial	0	++	0	0
• human	++	+	0	0
Competitive uncertainty	+	++	0	0
Consumer uncertainty	+	++	0	+
Supplier uncertainty	0	++	++	0
Political uncertainty	++	++	0	0

what technical parameters. After the emergence of a dominant design, technological uncertainty decreases while critical dimensions of merit upon which to evaluate technological options are settled and critical technical problems are defined. As the scale of application of the technology increases, experience and knowledge about the technology gradually build up and technological uncertainty decreases even more (as technologies move up the learning curve). However, the only component of technological uncertainty that remains equally dominant in all phases is uncertainty about the emergence of alternative technologies that make current technologies obsolete.[19] With respect to resource uncertainty, we distinguish between uncertainty about financial and about human resources. We expect that uncertainty about financial resources is most dominant in the take-off phase when mass-production of the product starts, requiring high investments. Furthermore, uncertainty about the payback of investments is high since competition is fierce in this phase.[20] We expect that uncertainty about human resources will dominate in the pre-development phase, when it is most difficult to assess which knowledge and skills are required and how these can be obtained, and gradually decline over time when the firm has developed an adequate knowledge base for carrying out the innovation process. Competitive uncertainty will likely dominate in the take-off phase, when competition between developers of established technologies as well as new technologies is fierce.[21] Consumer uncertainty is expected to dominate also in the take-off phase since in this phase the product enters the market and competition for the lead-users starts.[22] We reason that supplier uncertainty will dominate in the take-off phase and the acceleration phase, when the bargaining power of suppliers is high (Afuah and Utterback 1997). In the take-off phase, uncertainty arises about finding reliable suppliers that are able to deliver high-quality components in large quantities. In the acceleration phase, the relation between suppliers and technology developers has become embedded. In the case of highly specialized components, the dependency on a supplier is high, which increases supplier uncertainty.[23] Assumably, political uncertainty will play a dominant role in the pre-development phase and the take-off phase when policy is needed to stimulate the new technology (e.g. in the form of niche management or subsidies), and on the other hand, regulations may need to be changed before the new technology can enter the market. In the acceleration phase and the stabilization phase, political uncertainty might be less dominant as most political barriers have been resolved and stimulation of the technology is no longer needed. We expect that uncertainty about (unpredictable) policy changes remains equally present in all phases.[24]

Determining patterns of dominant types of uncertainty can provide essential insights for managing STTs. Namely, if indeed the dominancy of uncertainties changes in different phases of the transformation process, the portfolio of policy instruments also would have to be adapted for each of the phases of STT. In addition to developing a theoretical framework, as we did in this article, empirical research is necessary to identify patterns of uncertainty. Before we address some directions for further research, we discuss some of the major implications of uncertainty in STTs for policymaking in the final section.

2.5 Implications for policy and further research

STTs as we are discussing in this article are very complex and uncertain, which makes them difficult to manage. This raises the question of which management strategies (applied at the level of individual actors) and policy instruments (applied at the system level) have to be developed and used in order to contribute to an efficient and effective management of uncertainties regarding STT.

The first challenge that should be addressed when developing appropriate instruments for managing STTs is how to design and align strategies at and between the various levels of the innovation system. The complex interplay between the level of individual actors and the level of the innovation system makes policymaking very difficult (Kemp and Loorbach 2003). The second challenge relates directly to uncertainties concerning STT. As we mentioned above, innovation systems play an important role in STT. The growing influence of innovation systems emphasizes that these uncertainties not only relate to the knowledge and technology production component of the system, but also to many other actors and institutions. Furthermore, the systems approach makes clear that these uncertainties are strongly interrelated, which makes the challenge of designing effective policy instruments even more difficult to master. A third challenge is the lack of policy instruments that focus on the system level. Despite the growing awareness of the systemic character of innovations, till now the policy instruments are still strongly focusing on one organization or on bilateral relations (Smits and Kuhlmann 2004). Furthermore financial instruments still heavily dominate the policy portfolio (Boekholt, Lankhuizen et al. 2001). To cope with the challenges of STT, these instruments are insufficient. The rise of the systems of innovation approach and the growing insight that uncertainty and learning are inherent to innovation have lead to the awareness of the need of reorganizing the policy portfolio to tune it more to the demands that innovation systems pose. Smits and Kuhlmann (2004), in their analysis of the developments in innovation studies and the portfolio of instruments of innovation policy makers, as well as Koppenjan and Klijn (2004), who focus on managing uncertainties in the context of a network of actors, argue for the development and application of new management strategies. These strategies or instruments should focus, among others, on learning, building, breaking-down and aligning innovation systems, reframing of stakeholders' perspectives and joint production of knowledge.

Further research is necessary to fully understand and manage STT. Empirical studies, using Table 2-3 as a framework, are necessary to analyze whether and how different types of uncertainties indeed dominate in different phases of STT and for different types of actors. Furthermore, continuing theoretical and empirical research can help us deepen our insights into the strategies individual actors use in reaction to perceived uncertainties and into the policy instruments that should be developed to deal with uncertainties in STTs. In a future article, we will elaborate these issues further.

Notes

1 Although socio-technological transformation as a whole can be characterized as radical, the short-term innovations that collectively constitute the transformation do not all have to be radical.
2 These innovation decisions comprise both decisions to develop and to adopt innovations.
3 Distinguishing between various types of actors is not only important for identifying differences in perceived uncertainties, but also for designing steering arrangements. We will elaborate on the roles, positions and strategies of different actors involved in socio-technological transformation in a future article.
4 In our definition, ambiguity – the existence of different interpretations of an issue – is also included in the term 'uncertainty'.
5 The distinction between knowledge uncertainty and variability uncertainty is not sharp. Variability uncertainty contributes to knowledge uncertainty: due to variability, perfect knowledge and certain predictions are anyhow unattainable (Van Asselt 2000). But knowledge uncertainty can also exist in deterministic processes (e.g. due to a lack of communication, inexact measurements or too high complexity).
6 For instance, resulting from a lack of communication. (Williamson 1987)
7 Although each researcher uses his own conceptualization, we have grouped those concepts that appeared closely related. For example, Jennings and Jones (1999) speak about uncertainty regarding labour and capital markets, which we have assigned to 'resource uncertainty'.
8 See note number 1.
9 The third uncertainty that was mentioned was uncertainty about the lead-time of the nuclear power plant relative to the coal-fired plant, which was influenced by increased uncertainty about regulations. Uncertainty about regulations is a component of political uncertainty, as we will discuss below.
10 This cause of technological uncertainty can also be found in the description of 'action uncertainty' by Van Asselt (2000) and by Moenaert and Souder (1990) in their description of technological uncertainty as 'a lack of knowledge about technological solutions'.
11 See note number 1.
12 The difference between competitive uncertainty and technological uncertainty caused by the possibility of choosing alternative technological solutions is that competitive uncertainty refers to the actions of competing firms while technological uncertainty refers to the characteristics of competing technologies.
13 First mover advantages afford greater returns to a firm that acts before another firm, while economies of scale afford greater returns to a firm that invests more. In general, the greater the number of competitors, the greater the incentive to act early or to focus investments. (Wernerfelt and Karnani 1987)
14 Supplier uncertainty can be attributed to *external* availability and quality of goods and services (such as knowledge), whereas resource uncertainty relates to the availability of capital and knowledge *internal* to the organization.
15 Collaborating with other actors (such as suppliers, competitors, research institutes or consumer organizations) may not only help in reducing uncertainty about the behaviour of this actor, but also in coping with other sources of uncertainty (such as sharing uncertainty about financial resources).
16 Other actors instead of government can also create uncertainty if there is a discrepancy between what they say and what they do.
17 In follow up research this framework will be used in empirical case studies involving the transformation towards a sustainable energy system.
18 The dominant source is the source that is perceived as most important by the actor.
19 Since this component is equal in all phases, we have chosen not to take this component into account in our assessment. Therefore, the acceleration and stabilization phase are given a 0 instead of a +. The same holds for uncertainty about (unpredictable) changes in policy (a component of political uncertainty). Note that this is only an exemplary description of the pattern we expect to find.

20 We expect that uncertainty about financial resources will likely be less important in the pre-development phase, since the investments are then relatively small and will be funded from the R&D budget of the firm and/or from public funding. In the acceleration and the stabilization phase, the financial uncertainty will likely be relatively unimportant as well, since the firms that have survived the shake-out regarding the number of competitors are making profit and hardly have to invest anymore.

21 In the pre-development phase, technology developers will be uncertain which firms will bring a competitive technology on the market, how these competing technologies will perform and which strategies these competing firms will use. However, competitive uncertainty is less dominant in this phase in comparison with the take-off phase. In the acceleration and stabilization phase, competitive uncertainty will be less important compared to the previous phases, since firms know who their competitors are and what their strategy is.

22 In the pre-development phase, technology developers will try to anticipate on the consumers' expectations regarding the new technology. Since potential consumers are unable to clearly articulate their expectations and needs regarding the new technology, technology developers will perceive consumer uncertainty. However, in this phase technological uncertainty dominates over consumer uncertainty. In the acceleration phase, consumer uncertainty is low. In the stabilization phase, the market becomes saturated and technology developers will be uncertain on how to retain their market share. As a result, consumer uncertainty will become more important again.

23 In the pre-development phase, technology developers have the option of making prototypes in-house, without requirement of specialized components from suppliers. In the stabilization phase, only minor changes take place. Thus, we expect that supplier uncertainty is relatively small in these phases.

24 See note number 19.

Interlude A

In the previous chapter, a theoretical framework was presented for studying the role of perceived uncertainty in socio-technological transformation processes (also called "transitions"). The framework was based on two assumptions. The first assumption was that depending on the type of actor, different types of uncertainty will dominate their innovation decisions. The second assumption was that different types of perceived uncertainty will dominate in different phases (pre-development, take-off, acceleration and stabilization). In order to distinguish between different types of perceived uncertainty, perceived uncertainties were classified according to their nature (knowledge or variability), level (ranging from low to high) and source (technological, resource, competitive, supplier, consumer, and political uncertainty). It was argued there that the source of uncertainty can be seen as the first order classification (the 'variables') and the nature and the level of uncertainty as the second order classification (the 'dimensions' that constitute the variable; see Table 2-2).

In the next chapter, the results of the first empirical case study are introduced. The case deals with micro-CHP, an emerging, more sustainable energy technology which is still in the pre-development phase. The goal of this first empirical case study was twofold:

1. to analyze whether the theoretical framework was applicable in an empirical context
2. to analyze the role of perceived uncertainty in the development of micro-CHP.

With respect to the first objective, a set of both open and closed interview questions was used. First, the interviewees were asked to describe in their own words which types of uncertainty they perceived as important for their innovation decisions with respect to micro-CHP. Second, the distinction between nature, level and source of uncertainty was presented to the interviewees. The interviewees were asked to comment on each source of uncertainty in terms of:

- "How relevant is this source of uncertainty for your innovation decisions?"
- "Can you give examples of this source of uncertainty?"
- "Are there any sources of uncertainty missing from the overview?"

Then, the interviewees were asked to rank the six sources of uncertainty according to their relative importance. With respect to the nature of uncertainty, the interviewees were asked to indicate if the uncertainties they perceived could be reduced by collecting knowledge. With respect to the level of uncertainty, the interviewees were asked to make a distinction between small uncertainties (i.e. situations in which it was still possible to define different future scenarios and estimate their probabilities) and large uncertainties (i.e. situations in which this was not possible).

The distinction between different sources of uncertainty corresponded well to the uncertainty descriptions given by the interviewees. Furthermore, the interviewees valued all sources of uncertainty as relevant and no sources seemed to be missing. Therefore, it was concluded that the classification of six sources of uncertainty was useful for analyzing perceived uncertainties with respect to the development and implementation of emerging, more sustainable energy technologies. However, the interviewees clearly had difficulty in determining the nature and level of uncertainty. Hence, it was decided to focus on the classification of uncertainty sources for the remaining part of this thesis.

The second objective of the case study was to analyze the role of perceived uncertainty in the development of micro-CHP. More specifically, the case study aimed to analyze which types of perceived uncertainties played a dominant role in the innovation decisions of the various actors involved, how the different actors reacted to these perceived uncertainties, and if this actor behaviour stimulated or hindered the overall transition. The empirical outcomes of the micro-CHP case are reported in the following chapter.

3 The case of micro-CHP

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3.1 Introduction

The concepts 'transition', 'socio-technological transformation', and 'system innovation' have been receiving much attention in literature. (Rotmans, Kemp et al. 2001; Geels 2002a; Geels 2002b; Brown, Vergragt et al. 2003; Rotmans 2003; Van Lente, Smits et al. 2003; Elzen, Geels et al. 2004; Smith, Stirling et al. 2005) Recently, a special issue of this journal was dedicated to these topics (Elzen and Wieczorek 2005). A transition, as we will call it in this article, is defined as a major, long-term technological change in the way societal functions (such as the supply of energy) are fulfilled (Geels and Kemp 2000; Geels 2002a). Transitions that are initiated with a specific goal, such as the transition towards sustainability, are difficult to achieve (Kemp and Soete 1992; Grubler, Nakicenovic et al. 1999a; Jacobsson and Johnson 2000; Unruh 2000; Geels 2002a; Rotmans 2003; Jacobsson and Bergek 2004; Elzen and Wieczorek 2005). Therefore, much research has been focusing on gaining insight into the characteristics of transitions and on applying these insights in the development of strategies and policies to steer such transitions (e.g. (Elzen, Geels et al. 2004; Elzen and Wieczorek 2005)). One of the outcomes of this research, is that transitions have been characterized as consisting of several transition phases: pre-development, take-off, acceleration and stabilization (Rotmans, Kemp et al. 2001; Van Lente, Smits et al. 2003). This multi-phase conceptualization is helpful for analyzing transitions, but does not create insight into the underlying mechanisms that determine the dynamics of transition processes. In this article, we aim to contribute to a better understanding of these underlying mechanisms.

Starting point of this paper is that transitions are characterized by many uncertainties. These uncertainties play a key role, since they are considered to be one of the major blocking mechanisms of transitions (Kemp, Schot et al. 1998; Rotmans 2003; Jacobsson and Bergek 2004). Due to the long-time frame of transitions and the interrelatedness of technological and societal changes, uncertainty about the final outcome of a transition is large. Various types of actors each have their own vision of the future and these visions constantly change to adapt to new circumstances (Rotmans, Kemp et al. 2001). In order to reach each of the possible future outcomes, many separate innovation decisions (or 'transition steps') have to be taken (Suurs, Hekkert et al. 2004). It is the sum of these innovation decisions that leads to a transition. However, each of these innovation decisions is itself surrounded by uncertainties (e.g. (Nelson and Winter 1977; Dosi 1982; Freeman, Clark et al. 1982; Edquist 1997; Smits and Kuhlmann 2004)). The uncertainties that the actors involved perceive greatly influence their innovation decisions and thereby influence the transition as a whole. Thus, gaining insight into how perceived uncertainties influence innovation decisions and transition processes is important for better understanding the underlying mechanisms that determine transition processes.

Transitions involve a wide diversity of actors. While different actors each have their own perceptions of uncertainties, objectives, and resources, they will also apply different strategies to cope with perceived uncertainties. One of the standard responses to perceived uncertainties is to delay or even to abandon (innovation) decisions (Koppenjan and Klijn 2004). In other words, perceived uncertainties might prevent actors from participating in transition steps. Participating in transition steps in this respect means that actors fulfil certain key activities that are essential for the success of a transition. For example, perceived uncertainties might prevent actors from investing in experiments. Since the final outcome of a transition is uncertain, it is essential for transitions that many of these experiments in various directions take place. Thus, perceived uncertainties can block the fulfilment of key activities and thereby hamper the overall transition (Jacobsson and Bergek 2004). However, perceived uncertainties do not necessarily have to hinder a transition. Some scholars argue that uncertainty is a precondition for innovation (Clark 1985; Jauch and Kraft 1986). For instance, Jauch and Kraft (1986) argue that organizations in an uncertain environment tend to assume more risks and tend to be more proactive and innovative than organizations in a stable environment. Thus, instead of abandoning or delaying innovation decisions, actors can also accept that innovation is inherently uncertain and consciously deal with these uncertainties. To continue our example, perceived uncertainties can also form a driver for actors to undertake experiments in order to learn about the new technology and thereby reduce uncertainties. Thus, perceived uncertainties might also induce actors to fulfil certain activities that are essential for achieving a transition. In order to stimulate the transition towards a sustainable future, we therefore need to understand which uncertainties the actors involved perceive and whether or not actors' reactions to these uncertainties hamper the transition.

Although the importance of uncertainty in transition and innovation studies seems widely recognized (e.g. Nelson and Winter 1977; Dosi 1982; Freeman, Clark et al. 1982; Clark 1985; Edquist 1997; Rotmans 2003; Smits and Kuhlmann 2004), some authors argue that the concept of uncertainty is poorly elaborated in innovation studies (Fleming 2001; Corral 2002). The aim of this article is to come to a better understanding of the underlying mechanisms of transitions processes, by focusing on the influence of perceived uncertainties on innovation decisions. We build on a previous article, in which the argumentation was made that the type of perceived uncertainties will vary depending on the transition phase and the type of actor (Meijer, Hekkert et al. 2006). In this article, we aim to elaborate on these theoretical notions and to apply the previously developed typology of uncertainty sources (Meijer, Hekkert et al. 2006) to an empirical case. To keep research comprehensible, we thereby concentrate on only one transition phase: the pre-development phase. The empirical case focuses on an emerging technology that is currently in the pre-development phase, namely micro-CHP. Combined generation of heat and power (CHP), also known as cogeneration, means that electricity and heat are generated simultaneously. Up to now, CHP plants have been large-scale units used for industrial processes and district heating. Currently, progress is made to apply CHP on domestic scale (i.e. with an electrical power below 5 kW_e). This domestic application is called micro-CHP and is supposed to be a substitute for the high-efficiency boiler. The use of micro-CHP can lead to substantial energy savings and CO_x-emission reduction since the overall efficiency is higher compared to generating space heating, hot water and electricity separately and, due to the decentralized generation of electricity, distribution losses can be avoided. The development of micro-CHP in the Netherlands is an interesting case for studying the role of uncertainties in emerging transition technologies, since micro-CHP is considered as one of the promising innovations contributing

to the transition towards a sustainable energy system and many activities are currently taking place around this technology. The following research questions are posed:
Which types of perceived uncertainties are dominant for the innovation decisions related to micro-CHP in the Netherlands? How do actors react to the perceived uncertainties?

The methodology that we have applied for this research is outlined in Section 3.2. In Section 3.3, we describe the theoretical framework. The results of the empirical case are described in Section 3.4. We end our paper with the main conclusions and policy recommendations (Section 3.5).

3.2 Methodology

We have used a theoretical framework, described in Section 3.3, to study the relation between perceived uncertainties and actors' responses to these uncertainties. This framework was based on a review of uncertainty and innovation literature (see also Meijer, Hekkert et al. 2006). The data for the empirical case was collected by reviewing grey literature (newspaper articles, professional journals and policy documents) and interviewing the main actors involved in the development of micro-CHP. Since micro-CHP is still in the pre-development phase, the number of actors involved, and consequently the number of interviews, is limited. We made a distinction between four groups of actors: technology developers, potential adopters (i.e. buyers and users of the technology), intermediary organizations and governmental parties. We selected 10 interviewees who together form a good representation of the actors involved. All of the interviewees were well informed about micro-CHP, but not necessarily proponents of micro-CHP. We interviewed all technology developers who are undertaking activities in the Netherlands. The group of potential adopters consisted of organizations that can play an important role in generating intermediary demand for micro-CHP (i.e. energy companies and housing organizations). We were unable to interview end-users (house owners or tenants), as they have not taken notice of micro-CHP yet. The government was represented by a spokesperson of the ministry of Economic Affairs, who was concerned with the energy (transition) policy. Furthermore, we interviewed an expert on micro-CHP of the key intermediary organization for CHP in the Netherlands (Cogen Projects). The interviews took place in the summer of 2004. We did a follow-up interview with the interviewee of the intermediary organization, in order to verify our conclusions and inquire about recent developments.

The interviews started with a brainstorm question about perceptions of uncertainty. The answers to this question gave a good impression of the main uncertainties the interviewees perceived. In addition, this question served as a check to see if the uncertainties the interviewees mentioned corresponded with the typology of uncertainty sources used in the theoretical framework (see Section 3.3.1). In question 2, we introduced the typology of uncertainty sources and asked the interviewees to indicate if each of the sources was relevant for their innovation decisions and to give examples. In question 3, the interviewees were asked to rank the uncertainty sources according to their relative importance. Having identified the perceived uncertainties, we asked the interviewees which strategies they used for dealing with perceived uncertainties. In order to reduce the occurrence of strategically correct answers to this question, we verified the answers by reviewing grey literature on the strategies of the actors and by asking the interviewees not only about their own strategies, but also about the strategies of the other actors (triangulation). To prevent misinterpretations, all interviewees have reviewed the interview report. The interviews were analyzed qualitatively.

3.3 Uncertainty and transition

This section describes the theoretical framework that is used in this article to study the role of uncertainties in transitions. The theoretical framework consists of several parts. Section 3.3.1 introduces a typology of perceived uncertainties according to different uncertainty sources. Section 3.3.2 describes how actors can respond to perceived uncertainties, in terms of whether or not actors undertake certain key activities that are essential for achieving a transition. Section 3.3.3 discusses the role of uncertainties in the pre-development phase.

3.3.1 Sources of perceived uncertainty

In this article, the term 'uncertainty' is defined broadly as *"any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system"* (Walker, Harremoes et al. 2003, p5). It is important to note that gathering information cannot always reduce uncertainty. Uncertainty can exist even in situations where much information is available (Van Asselt 2000; Koppenjan and Klijn 2004). In our terminology, uncertainty also relates to aspects that are by definition indeterminable, such as the behaviour of other actors (March 1988; Koppenjan and Klijn 2004).

A continuing debate among scholars of uncertainty is the discussion about objective versus perceived uncertainty (e.g. Jauch and Kraft 1986; Kreiser and Marino 2002). Supporters of the objective view on uncertainty define uncertainty as a characteristic of the environment that can be measured objectively (Dess and Beard 1984). Supporters of the perceptive view on uncertainty argue that uncertainty is dependent on the individual and cannot be measured objectively (Milliken 1987). The term 'perception' refers to the process by which individuals organize and evaluate stimuli from the environment. The existence of information itself lacks meaning until an individual perceives it (Corrêa 1994). Environments are therefore neither certain nor uncertain but are simply perceived differently by different actors. In this article, we are interested in the innovation behaviour of actors. Namely, we want to analyze whether uncertainties stimulate or hinder actors from fulfilling certain key activities that are essential for achieving a transition. Since perceived uncertainties, and not objective uncertainties, influence this behaviour, we focus on 'perceived uncertainties'. In the remainder of this article, 'uncertainty' refers to 'perceived uncertainty'.

Having defined the concept 'perceived uncertainty', we can now introduce a typology of uncertainties. This typology is extensively described in (Meijer, Hekkert et al. 2006). We will classify perceived uncertainties according to their source. The source of uncertainty is the domain of the (organizational) environment which the decision-maker is uncertain about (Milliken 1987). Distinguishing between different sources of uncertainty is important for choosing appropriate strategies to cope with the uncertainty (Wernerfelt and Karnani 1987). The six sources of perceived uncertainty with respect to innovation decision-making are (Meijer, Hekkert et al. 2006):

1. **Technological uncertainty:** this uncertainty source includes uncertainty about the characteristics of the new technology (such as costs or performance), uncertainty about the relation between the new technology and the infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed) and uncertainty about the possibility of choosing alternative (future) technological options.
2. **Resource uncertainty:** resource uncertainty is uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation. Resource

uncertainty also includes uncertainty about how to organize the innovation process (e.g. in-house or external R&D, technology transfer, educating personnel). Resource uncertainty both resides at the level of the individual firm, as well as at the level of the innovation system.

3. **Competitive uncertainty:** whereas technological uncertainty includes uncertainty about competing technological options, competitive uncertainty relates to uncertainty about the behaviour of (potential or actual) competitors and the effects of this behaviour.
4. **Supplier uncertainty:** uncertainty about the actions of suppliers amounts to uncertainty about timing, quality and price of the delivery. Supplier uncertainty becomes increasingly important when the dependence on a supplier is high.
5. **Consumer uncertainty:** uncertainty about consumers relates to uncertainty about consumers' preferences with respect to the new technology, uncertainty about consumers' characteristics[1], and, in general, uncertainty about the long-term development of the demand over time.
6. **Political uncertainty:** political uncertainty comprises uncertainty about governmental behaviour, regimes and policies. Uncertainty can emerge about current policy (e.g. uncertainty about the interpretation or effect of policy, or uncertainty due to a lack of regulation) or about future changes in policy. Uncertainty about governmental behaviour (reliability of the government) is also an important cause for political uncertainty.

Since the technological development, the market and the networks of actors evolve in the subsequent transition phases, we expect that the dominance of the uncertainty sources will vary depending on the phase. Before we come back to this issue (in Section 3.3.3), we will look at how actors can respond to the uncertainties they perceive.

3.3.2 Functioning of innovation systems

Actors can respond to perceived uncertainties in many different ways. In this article, we are mainly interested in reactions to uncertainty that influence transitions. Therefore, we want to analyze whether perceived uncertainties stimulate or hinder the fulfilment of certain key activities that are essential for achieving a transition. Although each technological trajectory is unique with respect to the technological and institutional setting in which the transition takes place, the so-called 'innovation system'[2], recent innovation scholars have formulated a generic list of key activities that contribute to the success of transitions. Since these key activities have the function to contribute to the goal of the innovation system, which is the generation, diffusion and utilization of innovations, the term 'functions of innovation systems' or 'system functions' is used to describe the set of key activities (Johnson 2001; Jacobsson and Bergek 2004; Hekkert, Suurs et al. 2007). We distinguish the following system functions (Hekkert, Suurs et al. 2007):

1. **Entrepreneurial activities:** the role of an entrepreneur is to turn the potential of new knowledge development, networks and markets into concrete actions to generate and take advantage of business opportunities. Experimenting by entrepreneurs is necessary to collect more knowledge on the functioning of the technology under different circumstances and to evaluate reactions of consumers, government, suppliers and competitors.
2. **Knowledge development**: R&D and knowledge development are prerequisites for innovation. This function encompasses 'learning by searching' and 'learning by doing'.
3. **Knowledge diffusion through networks**: the exchange of information through networks of actors (research institutes, governmental agencies, consumers, entrepreneurs) contributes to 'learning by interacting' and, in the case of user-producer networks, 'learning by using'.

This function is especially important when a heterogeneous set of actors is involved in the innovation process.

4. **Guidance of the search**: since resources are limited of nature, it is important that, when various technological options exist, specific foci are chosen for further investments. Without this selection, there will be insufficient resources for the individual options. This function includes those activities that can positively influence the visibility and clarity of specific needs among technology users.
5. **Market formation**: new technologies often have difficulty competing with embedded technologies. Therefore, it is important to facilitate the formation of markets, e.g. by the formation of niche markets or by favourable tax regimes.
6. **Resources mobilization**: the allocation of sufficient resources, both human and financial, is necessary as a basic input to all the activities of the innovation process.
7. **Creation of legitimacy/counteract the resistance to change:** to develop well, new technologies often have to become part of an incumbent regime or even have to overthrow it. Parties with vested interest often oppose to this force of 'creative destruction'. In that case, advocacy coalitions can create legitimacy for the new technology by putting the new technology on the agenda and lobbying for resources and favourable tax regimes.

In this article, we use the term 'key activity' when we refer to the actor level and the term '(system) function' when we refer to the system level. If a system function is fulfilled well, this means that actors have undertaken many key activities that contribute to this function. To illustrate, attending a conference or organizing a workshop are examples of key activities that an actor can undertake, which contribute to the function 'knowledge diffusion'.

According to this functional approach to innovation system policy, stimulating transitions implies stimulating the fulfilment of the aforementioned system functions (Jacobsson and Bergek 2004; Jacobsson 2005; Hekkert, Suurs et al. 2007). Following Jacobsson and Bergek (2004), we add to this that uncertainties can be an underlying force that has a major influence on the functional pattern of innovation systems. Jacobsson and Bergek (2004) argue that high uncertainty in terms of technology, consumers and changing policy has hindered system fulfilment in the transition to renewable energy technologies. This would imply that policy aimed at stimulating transitions, should not only focus on the functions itself, but also take account of these uncertainties. If perceived uncertainties hinder the fulfilment of system functions, reducing the size of uncertainties or helping actors to cope with uncertainties may very well be an (indirect) way to stimulate desired functional patterns.

We expect that not only the dominance of the uncertainty sources, but also of the system functions will vary in different transition phases. In the next section, we take a closer look at the pre-development phase.

3.3.3 Uncertainties in the pre-development phase

This article focuses on the first transition phase: the pre-development or exploration phase.

The actors

The pre-development phase involves a wide variety of actors who each have their own objectives and play different roles in the transformation process. Because of these differences, we expect that various types of actors can have different perceptions of uncertainty. In other words, what is certain to one actor, does not have to be certain to another (Huff 1978).

As a result of the differences in objectives, perceptions and roles of the actors, we furthermore expect that the reactions' to perceived uncertainties can differ between the various actors involved. Whereas some actors might react to perceived uncertainties by delaying actions, others will react by undertaking key activities which contribute to the fulfilment of the system functions (see Section 3.3.2). What's more, distinguishing between the various types of actors helps to explain why some actors are more capable of undertaking certain key activities than others. For example, intermediary organizations will likely play an important role in fulfilment of the function 'knowledge diffusion', whereas technology developers will likely be better in 'knowledge development'.[3]

In short, we need to apply a multi-actor perspective in order to understand whether or not perceived uncertainties hinder the fulfilment of system function in the pre-development phase. Let us now describe some characteristics of this phase.

The pre-development phase

A new technological trajectory, and thus the pre-development phase, starts with the awareness that new directions are needed and new options and varieties emerge. This phase is characterized by basic R&D activities in which various routes and options are suggested and tried (Van Lente, Smits et al. 2003). Technological variety is large since various technology developers are working on competing products. These technological changes are interrelated to changes in the social dimension (Geels 2002a). User needs co-evolve with technical possibilities and new industrial networks emerge around the new technology.

The appearance of the first working prototype serves as a 'proof of principal' and is a powerful final signal to other technology developers that there will soon be a commercial product in the market (Suarez 2004). The ability of a firm to progress faster than competitors along a technological trajectory is seen as a crucial element in this phase (Suarez 2004). The pre-development phase ends when the first commercial product enters the market.

Based on these characteristics, we expect that some uncertainty sources will play a more important role than others in this phase. Below, we describe which uncertainty sources we expect to be dominant in the pre-development phase. We furthermore expect that these dominant uncertainty sources will influence the fulfilment of the system functions. Although Jacobsson and Bergek (2004) found empirical evidence that uncertainties can be an important blocking mechanism for the fulfilment of functions, how exactly these uncertainties influence the behaviour of actors in terms of the system functions is still an under-researched topic. Therefore, we do not hypothesize over the relation between the uncertainties and the system functions.

Dominant uncertainties

In the pre-development phase, the search for new technologies is still very diffused and firms have no clear idea where to place their R&D bets (Utterback 1994). Therefore, we expect that technological uncertainty will play a dominant role in this phase. For potential adopters (consumers and buyers of the new technology), technological uncertainty will relate to questions like "What can be expected of the new technology in terms of price, quality and other characteristics?". For technology developers, technological uncertainty relates to questions like "Is it possible to develop a working prototype?", "How will the technology function in real life situations?" and "Are we searching in the right direction or should we choose a different technological trajectory?".

We expect that uncertainty about the availability of resources to carry out the innovation process is also high in the pre-development phase. For technology developers and potential adopters, resource uncertainty will relate to the question "Which kind and which quantity of resources are necessary to develop or, respectively, to adopt, the new technology?". Resource uncertainty not only resides at the level of the individual firm, but also at the level of the innovation system. In this early phase, entrepreneurs will likely perceive uncertainty in not knowing what kinds of specialized competencies, basic knowledge or financial arrangements will emerge for the innovation at the system level (Van de Ven, Polley et al. 1999). Since the innovation has not yet entered the market, technology developers have no revenues during this phase. Van de Ven et al. (1999) explain that start-up funding for a venture represents an initial stock of assets that provides the entrepreneur a 'honeymoon period' to develop and commercialize its innovation. However, interest and commitment wane with time. When the honeymoon period is over, many innovation efforts are terminated since the progress that is made fails to live up to the expectations.

It is widely recognized that the emergence of a new technology is strongly influenced by the political climate (e.g. Marcus 1981; Van de Ven, Polley et al. 1999; Unruh 2000). Uncertainty if and how the government will support sustainable technologies like micro-CHP (e.g. uncertainty about acquiring subsidies, obstacles in regulation or political legitimacy for the new technology) can have a strong effect on the direction and speed of technology development. We therefore assume that political uncertainty will also play an important role in this phase.

Apart from technological, political and resource uncertainty, we furthermore expect that consumer uncertainty will play a dominant role in the pre-development phase. Since technological variety is still very large in this early phase and none of the prototypes is commercially available, consumers have difficulty in expressing their preferences and needs. Technology developers will likely perceive uncertainty about which technologies will best satisfy consumers' preferences and needs and how large the potential market for their product will be. Potential consumers can themselves also perceive uncertainty about the emergence of a market for the new technology.

Although there might be some competition amongst technology developers for who will be first in developing a successful prototype, uncertainty about the strategies of competitors will be less important for winning this R&D race than uncertainty about the technology itself, consumers, resources and politics. Therefore, we expect that competitive uncertainty will only play a modest role in the pre-development phase. We also expect that supplier uncertainty will hardly play a role in this phase, since dependence on suppliers' raw materials or equipment will be low. In this early phase, manufacturing of the technology will take place at very small scale (in laboratories).

To conclude this theoretical section, in the empirical case we aim to identify which uncertainty sources the various actors perceive and how these actors respond to the perceived uncertainties. By doing so, we aim to determine which uncertainty sources are perceived to dominate in the pre-development phase and whether these perceived uncertainties stimulate or hinder the fulfilment of system functions. We will formulate policy recommendations based on these insights.

3.4 Uncertainties related to micro-CHP

The case study that we discuss in this article is about the transition trajectory of micro-CHP in the Netherlands. Micro-CHP is the combined generation of heat and power on domestic scale (i.e. with an electrical power below 5 kW_e). We argue that micro-CHP is currently in the pre-development phase, because a working prototype has been developed but the first commercial product still has to enter the Dutch market.

In the Netherlands, the potential market for micro-CHP is high, as it is favoured by the dense gas infrastructure, the relatively cool climate (temperate marine climate with cool summers and mild winters), and the tradition of decentralized cogeneration (d'Accadia, Sasso et al. 2003). Since the use of micro-CHP can lead to substantial energy savings and CO_x-emission reduction, micro-CHP is seen as one of the promising technologies that can contribute to the energy transition. Within the framework of the Dutch 'energy transition policy', aimed at stimulating and managing the long-term transformation towards a sustainable energy system, much attention is being given to the application of micro-CHP (Rotmans 2003; Ministerie van EZ 2006). Recently, market parties involved in this policy framework have initiated several experiments with micro-CHP systems. The goal of these experiments is to set the transformation process in motion and to demonstrate the possibilities of micro-CHP.

Micro-CHP systems can be based on several technologies. The most important competing technologies are the Stirling engine, the gas engine and the fuel cell. Most activities in the Netherlands focus on the Stirling engine and fuel cell technologies. The Stirling engine micro-CHP system appears to be the first micro-CHP technology that will enter the Dutch market. Due to the high heat/power ratio (low electrical efficiency and consequently higher heat production for a given capacity), the Stirling engine system is best suitable for dwellings with a relatively high heat demand. The fuel cell system has a high electrical efficiency and appears to be the most promising technology in the longer term. However, the fuel cell systems are still in an earlier stage of development and will need some more time before they are commercially available.

The first generation of micro-CHP systems is fuelled by natural gas and has a connection to the electricity grid. A connection to the grid is necessary, since the upcoming micro-CHP systems are dimensioned on the heat demand of the household. This means that the installation turns on when the household demands heat. Only then, the installation delivers electricity. Therefore, back-up electricity is needed. Connecting the micro-CHP system to the grid enables the household to import part of its electrical needs from the grid. In addition, the household may also export surplus electricity back to the grid when the heat demand is large and the electricity demand is low.

Research is being conducted into the application of micro-CHP systems as a 'virtual power plant'. The 'virtual power plant' implies that a multitude of micro-CHP units, which are dimensioned on the electricity demand, is controlled and managed from a central and remote location. In this way, the set of micro-CHP units operates as a distributed large power plant with great flexibility to meet peaking electricity demand in a specific region. Besides, research is taking place to the use of sustainable fuels (biogas or pure hydrogen) instead of natural gas to increase CO_x-emission reduction even more. These developments make micro-CHP suitable for various scenarios of the energy transition (such as the scenario of a hydrogen economy or a completely decentralised sustainable energy system).

Although micro-CHP is seen as a promising technology for achieving a transition in the energy system, the path towards large-scale application of micro-CHP is still long and there are many uncertainties on the way. In Section 3.4.1, we describe which of the uncertainty sources the various actors involved perceived to dominate their innovation decisions. Then (Section 3.4.2), we focus on how the actors reacted to these uncertainties.

3.4.1 The dominant uncertainties

In this section, we first give a general overview of the case results by describing which uncertainty sources the various actors involved perceive as dominant. Then, we take a more detailed look at each of the dominant uncertainty sources.

The dominant uncertainty sources

The interview results indicated that technological uncertainty and political uncertainty are the most dominant sources of uncertainty in the micro-CHP case, followed by consumer uncertainty. Table 3-1 shows the results of question 3, in which the interviewees had to rank the six uncertainty sources according to perceived importance. In this table, we can observe that technological uncertainty and political uncertainty scored overall highest on importance (highest number of 'rank 1' or 'rank 2' scores), followed by consumer uncertainty. Four interviewees clarified there ranking by stressing that technological uncertainty and political uncertainty were far more important than the other uncertainty sources.

The importance of technological and political uncertainty as observed in question 3, was confirmed by the answers to question 1 (brainstorm question[4]), since most of the uncertainties that the interviewees described related to technology or politics.

The many empty cells at the bottom of Table 3-1 indicate that the interviewees had difficulty ordering the relatively unimportant uncertainty sources. However, Table 3-1 does show that resource uncertainty scores relatively low. This was again confirmed by the answers to question 1, since none of the answers to this question related to resource uncertainty.

Table 3-1 Relative importance of uncertainty sources (interview question 3).

Ranking	Actors									
	TD1	TD2	TD3	TD4	A1	A2	A3	A4	IO	Gov
1	P	T	T	T	Cs	Cs	T	P	T	Cs
2	Cs	S	P	P	T	T	P	T	P	R
3	-	P	Cs	Other*	P	S/Cp	R	-	Cs	-
4	-	Cp	Cp	-	Cp	S/Cp	-	-	Cp	-
5	-	R	R	-	R	P	-	-	S	-
6	-	Cs	S	-	S	R	-	-	R	-

Actors: TD = technology developer, A = potential adopter (energy company or housing organization), Gov = government (i.e. ministry of Economic Affairs), IO = intermediary organization
Ranking: 1 = highest importance, 6 = lowest importance
Uncertainty sources: P = political, Cs = consumer, Cp = competitive, R = resource, T = technological, S = supplier, Other* = uncertainty about the position of energy companies (especially with respect to energy company as 'owner/controller' of a group of micro-CHP systems).
The **empty cells** in Table 3-1 mean that the other uncertainty sources are perceived equally important or not relevant (e.g. political uncertainty is not relevant for the government).

The answer of the intermediary organization (IO in Table 3-1) should be interpreted slightly different. The intermediary organization did not rank the uncertainty sources according to uncertainties that were relevant for their own organization. Since this organization has a good overview of all the micro-CHP stakeholders, this interviewee ranked the uncertainty sources for the development of micro-CHP in general. Their ranking corresponded well to the answers of the overall importance of technological, political and consumer uncertainty.

The uncertainties that the government (Gov) perceived differ from the other actors (see Table 3-1). For the government, only two sources of uncertainty were relevant, namely consumer uncertainty and resource uncertainty. Government's decision to continue the experiments with micro-CHP within the 'energy transition policy' framework was dependent on the long-term prospects of micro-CHP. Consumer uncertainty and resource uncertainty both influence the long-term prospect of micro-CHP. The uncertainty about resources related to uncertainty whether technology developers are able to upscale their production-capacity. An even bigger uncertainty for the government was uncertainty about the creation of a market for micro-CHP in the Netherlands (e.g. how will the Dutch consumers react to micro-CHP and will the long-term demand for micro-CHP be large enough?) The other uncertainty sources were not relevant for governmental decision-making about micro-CHP (empty cells in Table 3-1).

To summarize the results so far, technological and political uncertainty seemed to be the most dominant uncertainty sources, followed by consumer uncertainty. The importance of technological uncertainty and political corresponded well to our expectations about the pre-development phase (see Section 3.3.3). However, resource uncertainty was overall perceived less important than we expected. Below, the uncertainty sources are described in more detail.

Technological uncertainty

The most important element of technological uncertainty was uncertainty about the technology itself, like: "How will micro-CHP systems perform in real-life situations?", "When will micro-CHP become a 'proven technology'?" or, more specific, "How will the (future) performance of micro-CHP systems be in terms of efficiency, investment cost, life span, maintenance, reliability, size and weight of the installation, level of noise, etc.?" This uncertainty was perceived equally important by all the actors (potential adopters as well as technology developers) and for all the different micro-CHP technologies (since none of the technologies is yet a 'proven technology').[5]

Uncertainty about the relation between micro-CHP and the technological infrastructure, another aspect of technological uncertainty, was perceived less important. Most of the interviewees did not foresee major technological difficulties connecting micro-CHP to the grid. Nevertheless, as we will describe below, the connection of micro-CHP to the grid does lead to substantial political uncertainties.

Uncertainty about alternative (future) technological options was also perceived less important in comparison to uncertainty about the technology itself. First of all, several interviewees explained that they cope with this uncertainty by keeping a number of options open instead of placing all their bets on one technology. This strategy seems logical for those actors that do not have a direct stake in the development of micro-CHP (like the potential adopters or the government). These actors can keep an eye open on various technologies without having to make large investments. However, also two technology developers indicated that they keep several options open. To illustrate, one of them has performed pilot projects with both the Stirling engine and the fuel cell micro-CHP system and has also invested in R&D projects with respect to the gas engine. Another explanation that was given for the small importance of uncertainty about alternative technologies, was that each technology (different micro-CHP systems as well as other competing technologies like heat pumps) can occupy its own niche in the market. As a result of differences in heat/electricity-performance between the different micro-CHP systems, one of the technology developers believed that each technology has its own area of application.

Political uncertainty

The other dominant source of uncertainty was political uncertainty. Many interviewees mentioned to be uncertain about the reliability of the government in general. Unexpected changes in policy, like the sudden ending of subsidy schemes for renewable energy, have led to a lack of faith in governmental policy and declining expectations about the new technology. This can be fatal for new technologies.

Not only uncertainty about subsidies, but also uncertainty about the energy taxes and electricity feed-in policy strongly influences the economic feasibility of micro-CHP. In the current situation, micro-CHP owners pay energy taxes twice: first on the natural gas that they convert to electricity, second on the electricity that they temporarily 'store' on the grid (by feeding electricity in and at another moment retrieving the same quantity of electricity back). Furthermore, it is still uncertain which price micro-CHP owners will receive from the energy companies for the electricity they feed into the grid.[6] Government regulation is necessary to solve this problem. At the moment of the interviews, this issue was still unsolved and proved to be a clear factor of uncertainty.

Other examples of political uncertainty were uncertainty about the incorporation and valuation of micro-CHP in energy saving norms, right of admission of micro-CHP installations to the grid and more general concerns on the vision of the Dutch government on sustainability and micro-CHP.

Consumer uncertainty

With respect to consumer uncertainty, we can see a clear distinction between the different types of actors. The technology developers were hardly uncertain about the development of the market over time. They seemed convinced that there will be a market for micro-CHP systems. According to these actors, the emergence of a market is only a matter of time. Most of them claimed that uncertainties about the preferences or characteristics of consumers were small and could be reduced by market studies or pilot projects. Only one technology developer (TD3 in Table 3-1) indicated that there were still major uncertainties about the market for micro-CHP. What is however striking, is that this technology developer deliberately ignored uncertainty about the market until the micro-CHP system will be ready for market introduction. Before then, the technology developer focused only on managing technological and political uncertainty.

While the technology developers seemed to have high expectations about the market for micro-CHP, the other actors (potential adopters, government and intermediary organization) were more restrained. These actors did perceive uncertainty about the development of a market, like how large and how fast this market will emerge. Two potential-adopters (A1 and A2 in Table 3-1) even considered consumer uncertainty as the most important uncertainty source. They both explained that if customers don't want micro-CHP, this will bring a stop to the entire development process. One of them argued that the lack of knowledge about micro-CHP among installation companies could become an important barrier for the creation of a market for micro-CHP. Installation companies need to be well-informed about micro-CHP, since they have to be able to install the micro-CHP systems and will only advise house owners to buy a micro-CHP system if they know and positively value the technology. Most installation companies won't pay much attention to new technologies until they are commercially available. Two technology developers (TD2 and TD3), the intermediary organization and the government shared this uncertainty.[7]

The remaining uncertainty sources

The other uncertainty sources, namely uncertainty about suppliers, competitors and resources, only played a modest role in this case. The relatively minor importance of supplier and competitive uncertainty in this phase corresponded to our expectations (see Section 3.3.3), but resource uncertainty was less dominant than we expected. Overall, organizations that have a high stake in the development of micro-CHP (like micro-CHP developers) also seemed to be willing to allocate resources and therefore do not perceive uncertainty about resources. Only one technology developer indicated that the availability of resources to continue their activities was a source of uncertainty. However, compared to the other sources of uncertainty, this source was relatively unimportant to the interviewee. The opposite reasoning holds as well: organizations that did not undertake many activities with respect to micro-CHP (like potential adopters) in this early phase, did not need many resources and therefore did not perceive resource uncertainty. Two potential adopters explained that they only watched the course of events, but were unwilling to invest in micro-CHP as long as it is an unproven technology.

Likely, competitive, supplier and resource uncertainty will become more important in later phases. To illustrate this, one technology developer (TD3) explained that in this phase the technology developers still cooperate (e.g. in the micro-CHP working group which is led by the intermediary organization) in order to jointly accelerate the development process of micro-CHP, but that competition and competitive uncertainty will become more important when the micro-CHP systems enter the market. Supplier uncertainty might also become more important as the market introduction draws near, since technology developers have to increase their production capacity. Two technology developers (TD1 and TD2) were already trying to enter into cooperation agreements with suppliers in order to produce micro-CHP systems on a large-scale level.[8] One of them perceived uncertainty about this.

3.4.2 Managing uncertainties

As we will illustrate below, the activities that the actors in the micro-CHP case undertook clearly focused on the uncertainty sources they perceived as dominant. Since the reactions to perceived uncertainties indeed varied between the different types of actor, we discuss which strategies were used to cope with perceived uncertainties for the different actor groups.

Technology developers

Technology developers consciously tried to deal with the uncertainties they perceived as dominant (i.e. technological and political uncertainty). In reaction to uncertainty about the (future) characteristics of the technology, they all performed R&D activities. These activities seemed successful, since progress has been made in terms of efficiency, reliability and life span of the micro-CHP systems and the focus of the R&D activities has been shifting more and more from basic R&D towards making the product ready for market introduction.[9] Thus, perceived technological uncertainty has induced these actors to undertake 'knowledge development'-activities (Function 2).

In reaction to perceived political uncertainty, the technology developers engaged in various activities to create legitimacy for micro-CHP (Function 7). The technology developers cooperated with each other and with potential adopters in the micro-CHP working group that is led by the intermediary organization. This working group acts as an advocacy coalition which aims to create legitimacy for micro-CHP by jointly lobbying for government support. Another example of an activity which aimed at creating legitimacy for micro-CHP, was the demonstration project that one of the technology developers initiated. The main goal of this project was to demonstrate that micro-CHP systems work in real-life situations ('proof of principal') and that the first commercial micro-CHP systems will soon enter the market.[10] In short, for technology developers perceived uncertainties induced function-fulfilment.

Potential adopters
In comparison to technology developers, the potential adopters were more passive in this phase. Their strategy can best be described as 'wait-and-see'. They did undertake some activities in order to stay informed about the developments of micro-CHP and to represent their interest, like participating in pilot projects and being member of the micro-CHP working group. However, they seemed unwilling to make large investments in micro-CHP while there are still major uncertainties. They have been delaying action until the uncertainties will be reduced by others (e.g. technology developers) or by time. Thus, for these actors perceived uncertainties seemed to hinder the fulfilment of system functions.

Government
The government has been stimulating the development of micro-CHP under the framework of the 'energy transition policy'. By expressing that micro-CHP is a promising technology and supporting experiments with micro-CHP, the government has helped to guide the direction of the search (Function 4). A strong and visible preference of the government for micro-CHP can positively affect the R&D priority setting and thereby might reduce uncertainty about the possibility of investing in different technological alternatives (i.e. technological uncertainty).

Guiding the direction of the search is, however, not enough. An important task of the government is to reduce political uncertainty. The lobbying activities of the micro-CHP working group seemed to be effective, since the government was well informed about the political uncertainties that the micro-CHP stakeholders perceive. The government was aware of their task in reducing uncertainties about subsidies, admission to the grid, the electricity feed-in policy and energy taxes. Furthermore, the government endeavoured to reduce uncertainty caused by unclear, inconsistent or a lack of regulation. For example, policy-makers and policy-executors have been brought together (in a so-called 'service point') to collaborate on reducing ambiguities in legislation. However, the government argued that stakeholders should realize that uncertainties due to changes in policy are inevitable and that stakeholders should anticipate these changes instead of calling the government unreliable. The government felt that stakeholders sometimes incline to shift all the financial risk on to the government or even try to hinder competition by unjustly pleading for governmental intervention. The government has been trying to convince stakeholders to cooperate and deal with uncertainties collectively, instead of waiting for the government to reduce all uncertainties. This statement points out that there is a tension between the government and the micro-CHP stakeholders with respect to who should take the lead in bringing about the uncertain transformation towards sustainability.

3.5 Conclusions

The central questions we posed in this article were:
Which types of perceived uncertainties are dominant for the innovation decisions related to micro-CHP in the Netherlands? How do actors react to the perceived uncertainties?

We conclude that the two most dominant uncertainty sources in the pre-development phase of micro-CHP are technological uncertainty and political uncertainty, followed by consumer uncertainty. The importance of political and technological uncertainty corresponds well with our expectations about the pre-development phase (see Section 3.3.3), but resource uncertainty was perceived less important than we expected.

The case showed that perceived uncertainties play an important role in innovation and transition processes. Namely, perceived uncertainties influence the fulfilment of system functions that are essential for achieving a transition. However, the relation between perceived uncertainties and system functions is not straightforward, as the case showed that reactions to perceived uncertainties differ largely between the types of actors. Technology developers, who all have a high stake in micro-CHP, consciously deal with uncertainties by undertaking all sorts of activities that contribute to the fulfilment of the system functions. The activities that these actors undertake clearly focus on the dominant uncertainty sources. In order to cope with technological uncertainty, technology developers invest in knowledge development (Function 2). In reaction to political uncertainty, technology developers aim to create legitimacy for micro-CHP (Function 7). Thus, perceived uncertainties form an incentive for technology developers to fulfil key activities and thereby stimulate the transformation process as a whole. Potential adopters, on the other hand, seem to follow a 'wait-and-see' strategy. They seem unwilling to make large investments in micro-CHP while there are still major uncertainties. Although they participate in some of the activities (like participating in the micro-CHP working group and participating in pilot projects), they seem to wait until the dominant uncertainties have been resolved by the other actors. Thus, perceived uncertainties seem to block potential adopters to fulfil system functions. Yet, if we look at the different roles and positions of technology developers and potential adopters, it is also logical that technology developers are more active in fulfilling key activities in this pre-development phase than potential adopters.

The role of the Dutch government has been quite limited in this early transition phase. Governmental action has not been enough to reduce the political uncertainties that play such a dominant role in the micro-CHP case. Despite the perceived uncertainties and the limited governmental initiatives to reduce these uncertainties, the transition process was not hampered since technology developers have been taking a leading role and are still making progress in the development of micro-CHP. However, we wonder if perceived uncertainties continue to induce the fulfilment of key activities in the following transition phases. The blocking effect of perceived uncertainties might increase once micro-CHP enters the take-off phase. For example, uncertainty about the electricity feed-in policy and energy taxes largely influences the economic feasibility of micro-CHP. If government still has not resolved this uncertainty once micro-CHP enters the take-off phase, this might become fatal for the emergence of a market. Thus, although the role of uncertainties in very early transition phases seems to be less crucial than in later phases, policy makers should start early with developing suitable instruments to reduce uncertainties or helping market parties in better coping with uncertainties.

Further research is needed into the role of perceived uncertainties in the following phases of the transformation process. It will be useful to compare the results of this case with cases that focus on different transition technologies. Continuing both empirical and theoretical work is necessary to deepen our insight into the role of uncertainties in transitions and how to manage these uncertainties.

Notes

1 For example, an important characteristic for energy technologies is the energy demand of consumers. Uncertainty about such characteristics can become a barrier in developing a product that is compatible with consumers' requirements.

2 The concept of 'innovation system' is a heuristic attempt developed to analyze all such societal subsystems, actors, and institutions contributing in one way or another, directly or indirectly, intentionally or not, to the emergence or production of innovation. (Hekkert, Suurs et al. 2007)

3 Although there is a logical relation between the type of actors and the activities they perform, this is not a simple one-on-one relation. Namely, the activities of one actor can contribute to multiple system functions and, likewise, one system function can be performed by multiple actors.

4 See Section 3.2 for a description of the interview questions.

5 One technology developer (TD1) currently only perceives uncertainty about two sources, namely politics and consumers. However, the other uncertainty sources did play a role when the company first considered investing in micro-CHP. At that time, technological uncertainty was perceived most important, followed subsequently by resource uncertainty, political uncertainty, supplier uncertainty, consumer uncertainty and, lowest importance, competitive uncertainty. The interviewee declares that most of the uncertainties have been resolved meanwhile.

6 For micro-CHP owners, an electricity feed-in price that is equal to the price a consumer pays for electricity (namely the commodity price, grid costs and energy taxes) would be most desirable. This equals that the electricity meter 'turns back' when electricity is feed into the grid. Energy companies, on the other hand, are not willing to pay back more than the commodity price. In the opinion of some energy companies, even a feed-in price equal to the commodity price of electricity would be too high since the supply of electricity produced with micro-CHP units creates more uncertainty for energy companies than electricity that they purchase or produce from large-scale production units.

7 Installation companies play two roles: first, installation and maintenance of micro-CHP systems and second, advising and selling micro-CHP systems to house owners (intermediate demand). According to the role, uncertainty about installation companies can either be seen as supplier uncertainty or as consumer uncertainty.

8 Micro-CHP systems consist of a micro-CHP unit (Stirling engine, gas engine, fuel cell) in combination with a conventional condensing boiler (that supplies the peak load). Micro-CHP developers often depend on suppliers for both the micro-CHP unit and the boiler in order to manufacture the micro-CHP system.

9 Recently (autumn 2005), the activities of the technology developers have shifted more and more to creation of a market for micro-CHP. For example, technology developers and the micro-CHP working group are trying to involve installation companies and several technology developers have signed cooperation agreements with suppliers.

10 Contrary to pilot projects, the primary goal of this demonstration project was not to test and improve the micro-CHP system. The micro-CHP system that was used for the demonstration project is not the system that the technology developer is going to develop further into a commercial product.

Interlude B

In the previous chapter (Chapter 3), the empirical outcomes of the first case study on micro-CHP were reported. In order to gain more insight into the influence of perceived uncertainties on the overall transition, the micro-CHP case analyzed whether perceived uncertainties stimulated or hindered the actors from undertaking certain key activities which are essential for achieving a transition (also called "Functions of Innovation Systems"). The conceptual model is graphically represented in Figure B-1 (see Section 3.3 for further explanation of the model).

The following chapter, Chapter 4, combines the outcomes of the micro-CHP case with the outcomes of the second case study on biofuels. Biofuels technology is, just as micro-CHP technology, still in the pre-development phase (the first technology development phase). In the biofuels case, the same conceptual model is applied as in the micro-CHP case (see Figure B-1). However, the focus and data collection procedure differed from the micro-CHP case. Whereas the micro-CHP case analyzed all six sources of perceived uncertainty (technological, resource, competitive, supplier, consumer, and political uncertainty), the biofuels case focused exclusively on one source of uncertainty which had proven to play a dominant role: political uncertainty (Suurs and Hekkert 2005). Furthermore, whereas the micro-CHP case provided a 'static' view of perceived uncertainties, in the biofuels case a first attempt was made to incorporate a more dynamic view on how perceived uncertainties and actor behaviour evolve over time. The data for this analysis was based on a review of grey literature (newspaper articles, professional journals, policy documents, etc.) on the developments of biofuels in the Netherlands from 1990 to 2005.

Since the chapter was originally written in article-format, the theoretical section and the description of the micro-CHP case largely overlap with Chapter 3. However, by combining the micro-CHP case with the new case on biofuels, the chapter reveals an interesting picture of the influence of governmental behaviour on the perceived uncertainties and actions of entrepreneurs involved in the development of these emerging technologies.

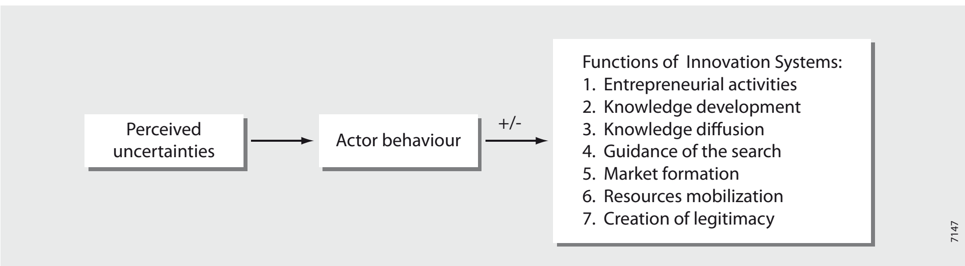

Figure B-1 Conceptual model of the micro-CHP case.

4 The cases of micro-CHP and biofuels

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4.1 Introduction

This article focuses on a particular aspect of sustainable development, namely sustainable technology development. The relation between technology and sustainability is complex and paradoxical (Grubler 1998). Apart from the advantage of creating economic growth and societal benefits, current use of technologies may cause severe environmental problems, such as pollution and depletion of resources. However, technologies may also lead to a more efficient use of resources, less stress on the environment, and cleaning of the environment. Thus, steering technological change towards sustainability – also referred to as 'sustainable technology development' (Weaver, Jansen et al. 2000) – is a fundamental part of governance for sustainable development.

In this article, we do not refer to technology development in the narrow sense, but to the development of technology in interaction with the socio-institutional system in which the technology is embedded (Hekkert, Suurs et al. 2007). Creating technological change aimed at sustainable development does not only involve technological change but also changes in the social and cultural dimension, such as user practices, regulation, and industrial networks (Geels 2002b; Elzen and Wieczorek 2005; Grunwald 2007). The increasing recognition among scientists and policy-makers of this system level of change has led to a rapid diffusion of concepts such as transitions or industrial or socio-technological transformation (Sagar and Holdren 2002; Geels 2002b; Elzen, Geels et al. 2004; Elzen and Wieczorek 2005; Smith, Stirling et al. 2005). A transition, as we refer to it in this article, is defined as a major, long-term socio-technological change in the way societal functions (such as the supply of energy) are being fulfilled (Geels 2002b). This long-term transformation at the level of society as a whole, in turn, consists of a sequence of short-term innovations (Geels 2002b).

The central idea of this special issue is that steering sustainable development is problematic due to the ambivalence of goals, the uncertainty of knowledge about system dynamics, and the distributed power to shape system development (Kemp and Soete 1992; Grubler, Nakicenovic et al. 1999b; Jacobsson and Johnson 2000; Unruh 2002; Geels 2002a; Voss, Newig et al. 2005)). First, the systemic character of transitions implies that a wide diversity of actors is involved and that none of the actors can achieve a transition alone (distributed power) (Smits and Kuhlmann 2004; Meijer, Hekkert et al. 2006). In other words, the behaviour of various actors collectively determines the speed and direction of a transition. Because actor-behaviour has such an important influence on the overall transition, this article aims to deepen our understanding of transitions by applying an actor-perspective. Second, due to the large diversity of actors, there are several perceptions of the final objective of the transition and these perceptions constantly change during the transformation process, in order to adapt to new situations (ambivalence of sustainability goals) (Rotmans, Kemp et al. 2001). In order to reach each of the possible objectives, many separate innovation decisions – decisions to develop or adopt a technological innovation that will contribute to the goal of the overall transition – have to be taken (Suurs, Hekkert et al. 2004). Thus, the ambivalence of sustainability goals leads to an infinite number of possible outcomes and an infinite number of possible innovation decisions. Third, due to the long time span of transitions and the co-evolution of technological and societal changes, knowledge of the dynamics of innovation systems is limited and uncertainty about the possible effects of innovation activities is high (uncertainty of knowledge about system dynamics; see also Grunwald 2007; Lange and Garrelts 2007). As a result, the actors involved in transition processes perceive great uncertainty, both about the final outcome of a transition and about each of the short-term innovation decisions. The uncertainties perceived by the actors play an important role, since they greatly influence the actors' decisions and behaviour. Perceived uncertainties can be regarded as positive when it stimulates actors to engage in novel sustainable technological trajectories. However, uncertainties may also have the effect that actors do not dare to invest in these desired directions of change. In that case uncertainties hinder actors to undertake activities that are essential for achieving a transition towards sustainability. Since the behaviour of individual actors collectively determines the speed and direction of a transition, these perceived uncertainties are likely to influence the transition as a whole. In order to improve our knowledge of the underlying system dynamics of transitions towards sustainability, insight into the various types of perceived uncertainties and actors' responses to these uncertainties is a prerequisite.

The aim of this article is to come to a better understanding of the influence of perceived uncertainties on the innovation decisions of actors involved in transition processes, in order to contribute to the difficult task of steering transitions towards sustainability. Ideally, governmental policy should contribute to the management of uncertainties, aiming at stimulating transitions. In some cases this implies that uncertainties need to be created in order to stimulate new directions of change and while in other cases governmental policy needs to be adapted when it is considered an important source of uncertainty that hamper transitions (Meijer, Hekkert et al. 2006; Meijer, Hekkert et al. 2007a). In this article, we aim to demonstrate which types of perceived uncertainties influence the innovation decisions of actors involved in sustainable technology development and how steering initiatives by the Dutch government influence these uncertainties, by examining two empirical cases of emerging sustainable energy technologies in the Netherlands. The first case concerns the development of micro-CHP (Combined generation of Heat and Power on domestic scale). The second case focuses on the introduction of biofuels (liquid fuels which are produced from biomass and used in the transport sector). In the Netherlands, expectations of the potential contribution of both micro-CHP and biofuels to the transition towards sustainability are high and many initiatives are currently being developed. However, since these technologies are still in an early stage of development, uncertainties about the future will likely be high. That makes micro-CHP and of biofuels interesting cases to study the role of uncertainties in emerging sustainable energy technologies. The main question of this article is:
Which types of uncertainties are perceived by the actors involved in emerging technological trajectories and how do they deal with these uncertainties?

Special attention is paid to the perspective of the entrepreneurs (the business firms involved in developing and implementing the new technology), since technological innovation cannot take place without entrepreneurs who dare to take action. In order to relate this entrepreneurial perspective to the governmental perspective, we also focus on how steering initiatives by the Dutch government influence the perceptions and behaviour of the entrepreneurs.

4.2 Uncertainty and transition

Transitions involve a wide variety of actors, each playing their own role in the transformation process. The most important role in technological innovation and transition processes is the role of the entrepreneur who turns the potential of new knowledge, networks, and markets into concrete actions to generate – and take advantage of – new business opportunities (Hekkert, Suurs et al. 2007). Different types of actors can perform the role of entrepreneur. Entrepreneurs can be technology developers wanting to market their technology, but they can also be adopters (buyers and users of the technology) who seek profit in the application of the technology.[1] Furthermore, entrepreneurs can be new entrants with visions of business opportunities in new markets, or established companies that diversify their business strategy to take advantage of new developments (Hekkert, Suurs et al. 2007). Because of differences in objectives, resources, and so on, we expect that different types of actors will have different perceptions of uncertainties and that they will react differently to perceived uncertainties. In this section, we describe the theoretical framework we used to study the different perceptions of uncertainties and the reactions of the entrepreneurs to these uncertainties in the empirical cases. This framework was based on a review of uncertainty and innovation literature, as reported in previous articles (Meijer, Hekkert et al. 2006; Meijer, Hekkert et al. 2007a).

4.2.1 Sources of perceived uncertainty

Uncertainty arises when the actors involved in a transition do not know what the effects of their innovation decisions will be. In this article, the term 'uncertainty' is defined broadly as "*any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system*" (Walker, Harremoes et al. 2003, p. 5). It is important to note that gathering information cannot always reduce uncertainty. Uncertainty can exist even in situations where much information is available (Van Asselt 2000; Koppenjan and Klijn 2004).

An ongoing uncertainty debate among scholars is the discussion about objective versus perceived uncertainty (e.g. Jauch and Kraft 1986; Kreiser and Marino 2002). Supporters of the objective view of uncertainty define uncertainty as a characteristic of the environment that can be measured objectively (Dess and Beard 1984). Supporters of the perceptive view of uncertainty argue that uncertainty depends on the individual and cannot be measured objectively (Milliken 1987). The term 'perception' refers to the process by which individuals organize and evaluate stimuli from the environment. The existence of information itself lacks meaning until an individual perceives it (Corrêa 1994). Environments are, therefore, neither certain nor uncertain but are simply perceived differently by different actors. In this article, we are interested in the innovation behaviour of actors. We intend to analyze whether uncertainties stimulate or hinder actors fulfilling certain key activities essential for achieving a transition. Since perceived uncertainties, and not objective uncertainties, influence this behaviour, we focus on 'perceived uncertainties'. In the remainder of this article, 'uncertainty' refers to 'perceived uncertainty'.

In this article, we classify perceived uncertainties according to each of its sources. The source of uncertainty is the domain of the (organizational) environment which the decision maker is uncertain about (Milliken 1987). Distinguishing different sources is important for choosing appropriate strategies to cope with the uncertainty (Wernerfelt and Karnani 1987). Based on an extensive literature review, which is reported in (Meijer, Hekkert et al. 2006), we propose the following set of uncertainty sources with respect to innovation decisions of entrepreneurs:

1. **Technological uncertainty:** this source includes uncertainty about the characteristics of the new technology (such as costs or performance), uncertainty about the relation between the new technology and the infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed), and uncertainty about the possibility of choosing alternative (future) technological options. Uncertainty about the direction of the transition process is reflected in this source of uncertainty.
2. **Resource uncertainty:** this source includes both uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation, and uncertainty about how to organize the innovation process (e.g. in-house or external R&D, technology transfer, education of personnel). Resource uncertainty both resides at the level of the individual firm, as well as at the level of the innovation system.
3. **Competitive uncertainty:** whereas technological uncertainty includes uncertainty about competing technological options, competitive uncertainty relates to uncertainty about the behaviour of (potential or actual) competitors and the effects of this behaviour.
4. **Supplier uncertainty:** uncertainty about the actions of suppliers amounts to uncertainty about timing, quality, and price of the delivery. Supplier uncertainty becomes increasingly important when the dependence on a supplier is high.
5. **Consumer uncertainty:** uncertainty about consumers relates to uncertainty about consumers' preferences with respect to the new technology, uncertainty about the compatibility of the new technology with consumers' characteristics[2], and, in general, uncertainty about the long-term development of the demand over time.
6. **Political uncertainty:** political uncertainty comprises uncertainty about governmental behaviour, regimes, and policies. Not only changes in policy, but also ambiguity in interpretation of current policy or a lack of policy can lead to uncertainty. Another important cause for political uncertainty is unpredictability of governmental behaviour. This source of uncertainty also reflects uncertainties related to the direction of transition processes. More specifically it relates to the uncertainty which transition directions are backed by government actions and support.

4.2.2 Functioning of innovation systems

Actors can respond to perceived uncertainties in many different ways. One of the standard responses to perceived uncertainties is to delay or even abandon (innovation) decisions (Koppenjan and Klijn 2004). In other words, perceived uncertainties might prevent actors from fulfilling certain key activities essential for achieving a transition, and, thereby, they might hamper the transition as a whole (Jacobsson and Bergek 2004). However, perceived uncertainties do not necessarily have to hinder transitions. Some scholars argue that organizations in an uncertain environment tend to be more proactive and innovative and tend to embrace more risks (Jauch and Kraft 1986). Instead of abandoning or delaying innovation decisions, actors can also accept that innovation is inherently uncertain and consciously deal with these uncertainties. For example, if an entrepreneur perceives high technological uncertainty about an innovative technology, the entrepreneur can either decide to abandon investments or to experiment in order to learn about the new technology and, thereby, reduce uncertainty. Thus, perceived uncertainties might also induce actors to fulfil activities that contribute to the overall transition.

Although each technological trajectory is unique with respect to the technological and institutional setting that influence the transformation process (the so-called 'innovation system'[3]), recent innovation scholars have formulated a generic list of key activities that are essential for achieving a transition. Since these key activities have the function to contribute to the goal of the innovation system, which is the generation, diffusion, and utilization of innovations, the term 'functions of innovation systems' (in short 'system functions') is used to describe the set of key activities[4] (Johnson 2001; Jacobsson and Bergek 2004; Foxon, Gross et al. 2005; Smith, Stirling et al. 2005; Hekkert, Suurs et al. 2007; Huang and Wu 2007). We distinguish the following system functions (Hekkert, Suurs et al. 2007):

1. **Entrepreneurial activities:** experimenting by entrepreneurs is necessary to collect more knowledge of the functioning of the technology under different circumstances and to evaluate reactions of consumers, government, suppliers, and competitors.
2. **Knowledge development**: R&D and knowledge development are prerequisites for innovation. This function encompasses 'learning by searching' and 'learning by doing'.
3. **Knowledge diffusion through networks**: the exchange of information through networks of actors (research institutes, governmental agencies, consumers, entrepreneurs) contributes to 'learning by interacting' and, in the case of user-producer networks, 'learning by using'. This function is especially important when a heterogeneous set of actors is involved in the innovation process.
4. **Guidance of the search**: since resources tend to be limited, it is important that specific foci are chosen for further investments when various technological options exist. Without this selection, there will be insufficient resources for the individual options. This function includes those activities that can positively influence the visibility and clarity of specific needs among technology users.
5. **Market formation**: new technologies often have difficulty competing with embedded technologies. Therefore, it is important to facilitate the formation of markets, e.g. by the formation of niche markets or by favourable tax regimes.
6. **Resources mobilization**: the allocation of sufficient resources, both human and financial, is necessary as a basic input to all the activities of the innovation process.
7. **Creation of legitimacy/counteract the resistance to change:** in order to develop well, new technologies often have to become part of an established regime or even have to overthrow it. Parties with vested interest often oppose to this force of 'creative destruction'. In that case, advocacy coalitions (Sabatier 1988a; Sabatier 1998b) can create legitimacy for the new technology by putting the new technology on the agenda and lobbying for resources and favourable tax regimes.

According to this functional approach to innovation system policy, stimulating transitions implies stimulating the fulfilment of the aforementioned functions (Jacobsson and Bergek 2004; Jacobsson 2005; Hekkert, Suurs et al. 2007). Following Jacobsson and Bergek (2004), we add to this that uncertainties can be an underlying force with a major influence on the functional pattern of innovation systems. Jacobsson and Bergek (2004) argue that high uncertainty in terms of technology, consumers, and changing policy has hindered system fulfilment in the transition to renewable energy technologies. This would imply that policy aimed at stimulating transitions towards sustainability, should also focus on the management of uncertainties to promote the fulfilment of system functions. In other words, if perceived uncertainties hinder the fulfilment of system functions, reducing the size of uncertainties or helping actors to cope with uncertainties may very well be an (indirect) way to stimulate desired functional patterns. In the following empirical cases, we aim to shed light on this issue by analyzing which types of uncertainties are perceived by the actors and how they respond to these uncertainties in terms of the fulfilment of system functions.

4.3 The case of micro-CHP

The first empirical case focuses on the introduction of micro-CHP in the Netherlands. Combined generation of heat and power (CHP), also known as cogeneration, means that heat and power are generated simultaneously. Up to now, CHP plants have been large-scale units used for industrial processes and district heating. Currently, progress is made to apply CHP on domestic scale (i.e. with an electrical power below 5 kW_e). This domestic application is called micro-CHP and is supposed to be a substitute for the high-efficiency boiler. The use of micro-CHP can lead to substantial energy savings and carbon emission reduction, since the overall efficiency is higher compared to generating space heating, hot water, and electricity separately. In addition, because of the decentralized generation of electricity, distribution loss can be avoided. Therefore, in the Netherlands, micro-CHP is considered one of the promising technologies able to contribute to the transition towards a sustainable energy system (Ministerie van EZ 2004; Ministerie van EZ 2006).

Below, we describe which uncertainty sources are perceived by the various actors as dominant, and whether or not these perceived uncertainties hamper the actors in fulfilling system functions. This is strongly based on (Meijer, Hekkert et al. 2007a). The data for this case was collected by studying grey literature and conducting interviews with the main actors involved in the development of micro-CHP. In order to have a good representation of the actor groups involved, an equal number of technology developers[5] and potential adopters (i.e. potential buyers and users of the technology, such as energy companies or housing organizations[6]) were interviewed. The set of interviewees also included a spokesperson of the Ministry of Economic Affairs who is concerned with the energy (transition) policy, and a spokesperson of an intermediary organization that plays an important role in diffusing knowledge and lobbying for CHP in the Netherlands. The interviews took place in the summer of 2004.

4.3.1 Perceived uncertainties

According to the interviewees, technological and political uncertainty appeared to be the most dominant uncertainty sources, followed by consumer uncertainty.[7] Uncertainty about resources, competitors, and suppliers only played a modest role in the micro-CHP case. Below, we describe the dominant uncertainty sources in more detail.

Technological uncertainty

Since micro-CHP is not yet a ‘proven technology’, the most important element of technological uncertainty was uncertainty about the technology itself (uncertainty about the future performance of the micro-CHP systems in terms of reliability, investment costs, energy efficiency, and so on). This uncertainty was perceived equally important by all the actors. Uncertainty about the relation between micro-CHP and the technological infrastructure and uncertainty about alternative (future) technological options were perceived as less important.

Most of the interviewees did not foresee major technological difficulties connecting micro-CHP to the electricity grid. Nevertheless, as we describe below, the connection to the grid does lead to substantial political uncertainties. The interviewees indicated not to perceive uncertainty about the choice between different technological options, since they keep several options open or believe that each technology can occupy its own niche market.

Political uncertainty

Many interviewees experienced uncertainty about the reliability of the government in general. This lack of faith is mainly due to unexpected changes in governmental policy which have occurred frequently over the past years. Several interviewees declared that such unexpected changes can have fatal consequences for emerging technologies by pointing out to the example of the sudden ending of many subsidy schemes for renewable energy by the Dutch government.

Apart from this general form of political uncertainty, the interviewees enumerated several specific policy issues that have created uncertainty in the development of micro-CHP, such as uncertainty about subsidies, energy saving norms, and legal admission of individual micro-CHP owners to the electricity grid. Of special importance to the development of micro-CHP is the uncertainty about the energy taxes and electricity feed-in policy, which strongly influences the economic feasibility of micro-CHP. At the moment of the interviews, it was still unclear how the application of micro-CHP would be incorporated in the energy regulation framework.

Consumer uncertainty

With respect to consumer uncertainty, we can see a clear distinction between the actors. Technology developers, on the one hand, seemed convinced about the emergence of a market for micro-CHP and believed it to be only a matter of time. Most of them claimed that uncertainties about the preferences or characteristics of consumers were small and could be reduced by market studies or pilot projects. Only one technology developer indicated that there were still major uncertainties about the market for micro-CHP. What is striking, though, is that this technology developer indicated to focus only on technological and political uncertainty and to simply ignore consumer uncertainty until the micro-CHP system will be ready for market introduction.

While the technology developers seemed to have high expectations about the market for micro-CHP, the other actors (the potential adopters, the government, and the intermediary organization) were more reserved. These actors did perceive uncertainty about the development of a market, for instance how large this market will be and how fast it will emerge. Two potential adopters even considered consumer uncertainty as the most important uncertainty source. They both explained that if consumers don't want micro-CHP, this will bring a stop to the entire development process.

4.3.2 Uncertainties in relation to system functions

Whether or not the perceived uncertainties have hindered the fulfilment of system functions, indeed depended on the type of actor in the micro-CHP case. Below, we compare the reactions of the two main market parties: the technology developers versus the potential adopters. Subsequently, we discuss the various initiatives by the Dutch government to reduce the uncertainties perceived by the market parties.

Technology developers versus potential adopters
Technology developers consciously tried to deal with the perceived uncertainties. Their activities clearly focused on the uncertainty sources that they perceived as most important, namely technological and political uncertainty. In reaction to technological uncertainty, they all initiated R&D activities. These activities seemed successful, since progress has been made in terms of the performance of the micro-CHP systems. Thus, technological uncertainty incited these actors to develop activities that contribute to the function of 'knowledge development' (Function 2, see Section 4.2.2).

In reaction to perceived political uncertainty, the technology developers expanded activities to create legitimacy for micro-CHP. The technology developers cooperated with each other and with potential adopters in a 'micro-CHP working group'. This working group, which was established by the intermediary organization, acts as an advocacy coalition aiming to create legitimacy for micro-CHP by lobbying for government support (Function 7). Another example of creating legitimacy was the demonstration project that was initiated by one of the technology developers. This project did not aim at improving the technology, but at bringing micro-CHP to the attention of potential adopters and policy makers and putting the regulatory problems concerning the electricity feed-in on the political agenda (Overdiep 2006). Thus, with respect to technology developers, perceived uncertainties stimulated the fulfilment of system functions.

In comparison to technology developers, the potential adopters turned out to be more passive. Their strategy can best be described as 'wait-and-see'. They have developed some activities in order to stay informed about the developments of micro-CHP and to represent their interest, such as participating in pilot projects and in the micro-CHP working group. However, they seem to be unwilling to make large investments in micro-CHP as long as major uncertainties remain. They delay action until the uncertainties will be reduced by others (viz. the technology developers) or by time. Thus, for these actors, perceived uncertainties seemed to hinder the fulfilment of system functions.

Government
The government has been stimulating the development of micro-CHP under the framework of the 'energy transition policy'. Transition management is a new Dutch governance approach, complementary to the regular energy policy, aimed at stimulating and managing the transition towards a sustainable energy system (Rotmans, Kemp et al. 2001; Rotmans 2003).[8] One of the basic assumptions of this approach, is that experiments help to deal with uncertainties about the long-term system change (Rotmans 2003; Voss, Newig et al. 2007). Within this policy framework, several micro-CHP experiments have been initiated (Ministerie van EZ 2004; Ministerie van EZ 2006). By stating that micro-CHP is a promising technology and by supporting experiments with micro-CHP, the transition policy of the Dutch government helps to guide the direction of the search (Function 4, see Section 4.2.2). A strong and visible preference of the government for micro-CHP can positively affect the R&D priority setting, thus reducing uncertainties about the possibility of investing in different technological alternatives (i.e. technological uncertainty).

Guiding the direction of the search, however, is not enough to stimulate emerging transition technologies. An important task of the government is to reduce the political uncertainty perceived by the market parties. On the one hand, the government has been aware of its task to reduce uncertainties about subsidies, the electricity feed-in policy, and so on. On the other hand, however, the government has argued that market parties should realize that uncertainties due to changes in policy are inevitable and that market parties should anticipate these changes instead of calling the government unreliable. This statement points out that there is a tension between the government and the market parties with respect to who should take the lead in bringing about the uncertain transition towards sustainability.

Overall, we conclude that the role of the government has been quite limited in this phase of the transition process. Although the government has stimulated micro-CHP in the 'energy transition policy' framework, governmental policy has not yet reduced the political uncertainties that play such an important role in the innovation decisions of the market parties. However, in this early transition phase, the expectations of micro-CHP seem high enough to counter the political uncertainties. Instead of a lack of function fulfilment, we notice a significant effort of technology developers to reduce existing uncertainties by fulfilling a number of system functions. Therefore, we conclude that, in this early phase, political uncertainty has no noticeable negative effect on the transition as a whole.

4.4 The case of biofuels

The second empirical case focuses on the transition towards the use of biofuels. The use of biofuels is considered a promising option for the transition towards a sustainable transport sector in the Netherlands. Biofuels are liquid fuels produced from biomass and used primarily for transportation. A distinction can be made between the first- and second-generation biofuels. The first-generation biofuels is produced with commercially available technologies for the conversion of sugars and canola oils into biofuels. The second-generation biofuels involves the conversion of woody biomass into biofuels, and is produced with advanced chemical or enzymatic technologies that are not yet commercially available. The advantages of the second-generation biofuels are that much higher volumes of biofuel can be obtained from one acre of land, and that the carbon emission reductions are much higher (minus 90%) compared to the first-generation biofuels (e.g. minus 30%) (Suurs and Hekkert 2005; Faaij 2006).

This case description is structured differently than the previous case on micro-CHP. In this case, we primarily focus on one type of uncertainty that has proven to be quite dominant, namely political uncertainty.[9] We discuss several examples of (a lack of) policy efforts of the Dutch government that have led to political uncertainties for the biofuel entrepreneurs. Furthermore, we analyze the consequences of these perceived uncertainties in terms of the activities of the various actors (especially entrepreneurs) involved in the transition. Since the perceived political uncertainty changes over time, we analyze three periods that differ in terms of political climate. The data for this case were based on a review of grey literature (newspaper articles, professional journals and policy documents), reported in (Suurs and Hekkert 2005). The literature study resulted in a chronological overview of activities developed by the various actors involved (i.e. governmental institutions, entrepreneurs) in the Netherlands in the period 1990-2005. From this overview, we have analyzed how various steering initiatives by the Dutch government have influenced the perceived uncertainties and behaviour of the actors involved.

4.4.1 Uncertainty about the general support of biofuels (1990-1995)

The first initiatives regarding the use of biofuels in the Netherlands started in the early 1990s. A few public transport companies and local authorities initiated experiments in which they adopted the new fuels. Driving force behind these experiments was the EU's political pressure to stimulate the use of biofuels, and the successful developments in Germany and France. The EU contributed to the financing of these experiments (ANP 1994).

Initially, these experiments did not lead to a general take-off of the transition to biofuels. Further expansion of activities was severely slowed down by the high prices of biofuels (Rotterdams Dagblad 2004) and by the unwillingness of the Dutch government to compensate for these higher prices (ANP 1993). In the Netherlands a fierce debate took place on the desirability of biofuels. Environmental organizations and academics questioned the environmental performance of biofuels from sugar beets and canola (the first-generation biofuels). On the one hand, EU guidelines forced the Dutch government to stimulate the use of biofuels, but, at the same time, the government was also confronted with a lobby against the present production methods of biofuels. This created a climate in which there was a lack of clear policy regarding biofuels. Since government support of biofuels was necessary to compensate for the higher production costs, this led to a poor entrepreneurial climate. A tax reduction on biofuels would lead to competing prices with conventional fuels but, at this point in time, a general tax exemption was no political reality (ANP 1993). The hope for better circumstances remained, due to increasing pressure of the EU on member states to implement policies stimulating biofuels.

Uncertainties about the future of biofuels in the Netherlands led to an agricultural lobby in support of biofuels (Trouw 1995). The agricultural sector was interested in biofuel production, since farmers could collect EU subsidies for producing non-food crops, and they could generate additional turn-over by selling feedstock for biofuel production. Eventually, this led to tax exemptions for some bio-diesel experiments (Het Financieele Dagblad 1995). These experiments were quite successful and triggered more activities in terms of lobbying (ANP 1997; NRC Handelsblad 1999), research (Trouw 1995; ANP 1996; De Volkskrant 1998), and coalition forming (Function 7, 2 and 3, see Section 4.2.2). The lobby proved to be successful when regulations for experiments with tax-free bio-diesel for trucks passed parliament (Trouw 2001).

Thus, the political climate in this period can be characterized by the situation that some projects received a temporary tax reduction, yet there was a general uncertainty about the potential of tax reduction for new projects and a follow-up of tax reductions when the permits granted would end. On the one hand, this political uncertainty slowed down the take-off of the use of biofuels but, on the other hand, this led to actions by entrepreneurs to influence the political climate and to experiments to show the benefit of the new technology.

4.4.2 Uncertainty about the direction of the transition process (1995-2002)

The next transition phase was characterized by a clear preference of the Dutch government for the second-generation biofuels. This preference found its origin in the strong lobby of academics and environmental NGOs against first-generation biofuels. With the second-generation biofuels still in the R&D stage, this period was characterized by a significant research effort which was partly financed by the Dutch government (De Volkskrant 1998). Thus, uncertainty about the technological feasibility of second-generation biofuels was countered by R&D activities (Function 2) and the formation of R&D collaborations (Function 3). The parties involved were mainly large vested firms with stakes in the oil, alcohol, and technology development business. Only one starter was part of this process, yet this was a spin-off of the multinational Royal Dutch Shell (De Volkskrant 1998). Generally, the parties involved in second-generation biofuels were not involved in first-generation biofuels. The only exception was Nedalco, a producer of alcohol that was interested in both (first and second-generation) methods to produce bio-ethanol (Het Financieele Dagblad 1996; Duurzame Energie 1997a).

For entrepreneurs involved in the first-generation technology, this new line of governmental policy created large uncertainties, since the future role of first-generation biofuels was strongly questioned and an alternative solution was offered. As a result, the progress in first-generation technology development and adoption stagnated in this period.

4.4.3 Uncertainty about market formation (2002-2005)

The significant R&D initiatives led to a 'proof of principle' for several second-generation technologies. The Dutch government reserved resources for contributing to the construction of a pilot plant. However, none of the market parties showed any interest (NOVEM 2002). The main argument of the market parties was that they perceived uncertainty about the size of the Dutch market for biofuels. Up to this point, the government had never put in a serious effort to create a market for biofuels by means of a general tax exemption or by setting a standard for a fixed share of biofuels in automotive fuels. In this case, the strategy of the Dutch government to invest in R&D instead of investing in a market for biofuels, turned out not to be successful. Even though the R&D initiatives led to considerable knowledge development (Function 2), the final step towards the market was not taken.

Meanwhile, activities related to the first-generation biofuels started to pick-up again. One of the reasons for this, was that the pressure of the EU on the Dutch government increased considerably. Since the technology development of second-generation biofuels proved to be too slow to meet the EU directive, the government decided to fall back on the first-generation and to allow first-generation technology to be part of the R&D program (Suurs and Hekkert 2005). This proved to be a major boost in creating legitimacy for this technology (Function 7). In addition, two players became very active in promoting first-generation technology.

The first actor was a firm called SolarOilSystems that decided to build a biofuel mill based on canola (Bizz 2002; NOVEM 2005). SolarOilSystems managed to create considerable local support from state authorities and agricultural organizations, to successfully lobby for tax exemptions, and to successfully build customer networks to create total production and consumption chains. Influenced by this example and by the expectation that the EU directive would be implemented in the Netherlands in 2004, seven oil mills were built.

The other active entrepreneur was Nedalco, a Dutch producer of alcohol. Nedalco was involved in the second-generation R&D program to produce ethanol from wood, but simultaneously lobbied for better market conditions for first-generation bio-ethanol based on sugar beets. The firm's commercial interest in the production of bio-ethanol was large, due to the potential increase of its production capacity, leading to lower production costs and higher profits. Nedalco managed to lobby for a temporal tax exemption for a fixed amount of ethanol and some R&D subsidies. (Suurs and Hekkert 2005)

In 2005, the Dutch government realized it needed to put in a serious effort to come up with a long-term vision regarding biofuels in the Netherlands. Since the R&D trajectory had proven to be too slow, the government switched from R&D stimulation to market stimulation by means of a tax exemption (up to 70 million Euros) for all biofuels in 2006 and an obligation for oil companies to mix 2% biofuel in automotive fuels in 2007.

At this moment in time, it is too early to tell how these market stimulation instruments will influence entrepreneurs' activities. However, Nedalco has stated that this policy does not provide sufficient certainty to invest in a bio-ethanol plant. For Nedalco, sufficient contracts with potential customers of bio-ethanol will need to be signed.

This period shows a remarkable difference between the behaviour of entrepreneurs under similar regimes of political uncertainty. Established firms with a small interest in these developments postpone investments, as market conditions are uncertain. Nedalco, an established producer with high stakes in these new developments, initiated significant lobbying activities but is unwilling to invest under uncertain market conditions. Finally, we see small entrepreneurs, new entrants, willing to invest even though market uncertainties are considerable, and quite actively influencing their environment. One possible explanation for the difference in behaviour is the required capital investment in technology. For Nedalco and the second-generation technologies, investments are exorbitant, while first-generation technology is relatively low-tech, resulting in lower investment costs.

4.5 Conclusions

The aim of this article was to come to a better understanding of the role of uncertainties in transitions, by examining two empirical cases about emerging energy technologies in the Netherlands. We posed the following research question: *Which types of uncertainties are perceived by the actors involved in emerging technological trajectories, and how do they deal with these uncertainties?*

The micro-CHP case demonstrates that different types of perceived uncertainties influence the innovation decisions of the actors involved. The most dominant sources of uncertainty in this case are technological and political uncertainty, followed by consumer uncertainty. Furthermore, this case shows that responses to uncertainty differ considerably between different actors.

Technology developers who have a high stake in the development of micro-CHP actively try to cope with perceived uncertainties by developing certain key activities that contribute to the functioning of the innovation system. In reaction to technological uncertainty, they initiate knowledge development activities. In reaction to political uncertainty, the technology developers initiated activities to create legitimacy for micro-CHP. In short, perceived uncertainties seem to stimulate the fulfilment of system functions by technology developers. The potential adopters of micro-CHP, on the contrary, seem to follow a wait-and-see strategy. They do develop some activities, such as participating in demonstration projects initiated by technology developers, but are unwilling to actively invest while they still perceive major uncertainties. Thus, for these actors, perceived uncertainties seem to hinder the fulfilment of system functions.

The role of the Dutch government has been quite limited in this early transition phase. Governmental action has not been sufficient to reduce the political uncertainties that play such a dominant role in the micro-CHP case. Despite the perceived uncertainties and the limited governmental initiatives to reduce these uncertainties, the transition process has not been hampered since technology developers have been playing a leading role and are still making progress in the development of micro-CHP. However, as we discuss below, the blocking effect of political uncertainties might increase once micro-CHP becomes ready for market introduction.

Comparing the micro-CHP case to the biofuels case, we see some remarkable similarities and differences. First, we notice that – just like in the micro-CHP case – the biofuels actors react differently to perceived uncertainties. Similar perceptions of uncertainty about the size of the future market made some entrepreneurs decide not to invest in the production of biofuels, while others did invest in production facilities. The size of the initial investments and the ability of the entrepreneurs to build networks with early adopters seem to be crucial in these decisions. We also observe that it those who decide to invest are especially the new entrants, while the larger incumbent players behave more risk averse. This acknowledges the often-described principle that small new entrants are more capable developing flexible strategies in fast changing markets than large, established firms.

Another similarity is that the high level of political uncertainty in the biofuels case did not lead to a lack of key activities. In fact, many lobbying activities (contributing to the system function 'creation of legitimacy') and a significant number of research activities (i.e. 'knowledge development'- function) are observed. However, compared to other countries, the number of entrepreneurial activities in the Netherlands has been quite low. Countries like Germany, France and Austria show a much higher diffusion of biofuels then The Netherlands (Suurs and Hekkert 2005). We observe that the large political uncertainties have hindered the diffusion of biofuels in the Netherlands, and that uncertainties hinder crucial system functions (e.g., entrepreneurial activities). This differs from the micro-CHP case, where these patterns could not be found.

Even though entrepreneurial activities are hindered by political uncertainties, the actors in the biofuels case seem to be stimulated to develop other activities with the aim of countering these uncertainties. Political uncertainty seems to induce lobbying activities in order to reduce these political uncertainties and technological uncertainties seem to lead to activities that are typical for early transition-phases like knowledge development. This is in line with our findings in the micro-CHP case. Micro-CHP is in an early stage of transition as well, and in this case we also see that activities are developed to counter specific uncertainties (e.g., knowledge development to counter technological uncertainty, and networking and lobbying to counter political uncertainty).

The biofuels case also showed that, as a technology further develops and becomes suitable for entering the market, the uncertainties seem to have a greater influence than in earlier phases of a technological trajectory. In this case, large uncertainties hamper the fulfilment of crucial system functions. A logical explanation for this phenomenon is stated by an important biofuel entrepreneur. He states that, when a biofuel firm is in the phase of entering a market with a new product, much more resources and management commitment are needed than in earlier phases. Before entering a market, a solid business-case needs to back-up investment plans and convince the management. Since large uncertainties have a major impact on the robustness of the business-case, the influence is larger in this setting than in earlier phases (Suurs and Hekkert 2005).

It is always difficult to generalize the results of two case studies. Our findings show a number of similarities between the two cases. Since the two cases are very different in terms of involved networks and technological domain, these similarities may well hold for other emerging technological trajectories as well. The differences between the case studies may be explained by the difference in transition phase but also by case specific circumstances. More case studies are necessary to be capable to generalize the results to all emerging technological trajectories.[10]

What are the implications for policy? First, the empirical cases have shown that perceived uncertainties play an important role in innovation and transition processes. Second, in early phases of transition, the role of uncertainties seems to be less crucial than in later phases. This is an important observation for policy makers since we have also shown that political uncertainties can greatly hamper entrepreneurial activities and thereby market introduction of sustainable technologies. Policy makers should therefore be very active in the phase just before and during market introduction to communicate well with the entrepreneurs about their perception of crucial uncertainties and develop policy instruments to (temporarily) bring down the level of uncertainties. Due to the large diversity of the types of uncertainties that are being perceived and the effects of these uncertainties on the behaviour of the actors involved, it is impossible to design a simple and generally applicable policy strategy. In order to effectively deal with uncertainties in transitions, we recommend developing a portfolio of various steering instruments that can be applied in different situations. Looking at the framework of steering theories as proposed by Voss and colleagues (Voss, Newig et al. 2007), this portfolio may contain elements of all clusters of steering strategies. For example, providing guidance can help to reduce uncertainty about the direction of technological development, building actor networks can reduce uncertainty about the behaviour of others (such as competitors or consumers), and so on. In order to improve our ability to steer transition towards sustainability, more insight is needed into the influence of different steering strategies on actors' perceptions of and reactions to uncertainties.

Notes

1 Non-commercial adopters are not considered entrepreneurs.

2 For example, an important consumers' characteristic for energy technologies is the energy demand.

3 The concept of 'innovation system' is a heuristic attempt developed to analyze all such societal subsystems, actors, and institutions contributing, in one way or another, directly or indirectly, intentionally or not, to the emergence or production of innovation. (Hekkert, Suurs et al. 2007)

4 The term 'key activities' is used when referring to the actor level and the term 'functions' when referring to the system level. If a function is fulfilled well, this means that actors have developed many key activities that contribute to this function. To illustrate, attending a conference or organizing a workshop are examples of actors' key activities that contribute to the function of 'knowledge diffusion though networks'.

5 All four technology developers that were at the time developing activities in the Netherlands were interviewed.

6 The group of potential adopters consisted of organizations that can play an important role in generating intermediary demand for micro-CHP (i.e. energy companies and housing organizations). We were unable to interview end-users (house owners or tenants), as they have not been involved in the development activities and have not yet taken notice of micro-CHP.

7 Most of the uncertainties that the interviewees mentioned (without having knowledge of our typology of uncertainty sources in this stage of the interview) related to technology or politics. When the interviewees had to rank the uncertainty sources according to their relative importance, technological uncertainty and

political uncertainty scored overall highest, followed by consumer uncertainty. Four interviewees clarified their ranking by stressing that technological uncertainty and political uncertainty were far more important in this early stage of development than the other uncertainty sources.

8 Whereas the regular energy policy is aimed at short-term goals (approximately 10 years from now), the energy transition policy focuses on the long term. The energy transition policy is based on a different, more process-oriented, governance approach. Some key elements of the 'energy transition policy' involve heterogeneous actors, stimulating learning processes, and creating a wide playing field. For a comparison between the two approaches, see (Rotmans 2003).

9 The alternative focus is a direct result from differences in research strategy. Contrary to the CHP case, the biofuels case was analysed according to functions of innovation systems method as reported in Suurs and Hekkert (2005). Due to these differences in data collection methodology we are not able to order the importance of the different uncertainties. However, the data allows us to analyse the effect of different uncertainties on entrepreneurial action. The emphasis is on political uncertainties due to a bias in data availability.

10 In the research program that led to this article, additional case studies are being performed on uncertainty perception in technological trajectories around biomass gasification and biomass combustion.

Interlude C

The previous cases on micro-CHP and biofuels focused on emerging technologies that were (in the period studied) still in the pre-development phase. The pre-development phase is primarily characterized by basic R&D activities and prototype development. The next chapter focuses on the development and implementation of biomass gasification, a technology that has entered the second phase: the take-off phase. In the take-off phase, the emerging technology has entered the market and the first adopters start buying and using the technology.

An important lesson from the case study on biofuels, which was reported in the previous chapter, was that the perceived uncertainties and the actions of entrepreneurs are not stable but evolve over time. The case on biomass gasification aims to provide a better understanding of how such changes come about. Although the conceptual model which was applied in the previous cases (see Figure B-1 in Interlude B) was useful for understanding how the actors' reactions to perceived uncertainty relate to the overall transition, not so much insight was gained on how changes in perceived uncertainties and actor behaviour occur. In addition, not so much attention was paid to the underlying aspects that explain why some actors decide to take action under uncertainty whereas others do not. In order to address these issues in more detail, the focus of the following chapter shifts from the relation between perceived uncertainty and the fulfilment of System Functions to the underlying factors influencing perceived uncertainties and entrepreneurial action. To do so, the chapter zooms in on entrepreneurial projects aimed to develop and implement biomass gasification plants, and introduces a more complex conceptual model for analyzing the influence of perceived uncertainty on the actions of the entrepreneurs involved.

5 The case of biomass gasification

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5.1 Introduction

The ever-growing body of literature on innovation and entrepreneurial decision-making reveals that there is a large and diverse set of factors influencing the decision of entrepreneurs whether or not to engage in innovation activities. These numerous factors range from characteristics of the innovation itself (e.g. the distinction between radical versus incremental innovations or the relative advantage of an innovation compared to established technologies, Dewar and Dutton 1986; Henderson and Clark 1990; Rogers 1995) to characteristics of the decision-making actor (such as personal or cultural characteristics that distinguish entrepreneurs from non-entrepreneurs or innovators from laggards, Brockhaus 1980; Rogers 1995; Shane 1995), characteristics of the environment in which the entrepreneur is operating (e.g. the stability of the market demand or the degree of competition, Porter 1980; Teece, Pisano et al. 1997), and so on. However, independent of the type of actor, the type of innovation or the type of environment, all innovation decisions inherently involve uncertainty (Nelson and Winter 1977; Dosi 1982; Rosenberg 1996; Edquist 1997). Therefore, uncertainty is considered a very important factor to focus on in order to gain a better understanding of innovation decisions.

The intrinsically uncertain character of innovation decisions, is particularly true for innovation decisions concerning emerging technologies; i.e. technologies that are still in an early phase of development (Van Merkerk and Van Lente 2005). On the one hand, the high degree of uncertainty surrounding emerging technologies signifies the large range of opportunities that a new technology has to offer. On the other hand, though, this uncertainty poses a threat of not knowing what comes next and not being able to *ex ante* determine the success or failure of a technological path (Garud and Rappa 1994). To phrase it differently, uncertainty can both create opportunities for entrepreneurs to engage in emerging technologies, as well as hamper entrepreneurs in undertaking action. Thus, the relation between uncertainty and the decision of entrepreneurs to engage in emerging technologies is very complex.

While the emergence of new technologies in general is a long and uncertain process, this appears to be particularly true for the development and diffusion of emerging renewable energy technologies (Jacobsson and Johnson 2000). Due to the urgent problem of climate change, there is a growing need for the application of renewable energy technologies. However, despite their large environmental benefits, large-scale implementation of emerging renewable energy technologies has proven to be difficult (Jacobsson and Bergek 2004; Raven 2005; Negro 2007). In 2004, the share of renewables in western countries accounted for only 5,7% of the total primary energy supply (IEA 2007). Several authors have argued that uncertainty is one of the major barriers hampering the breakthrough of emerging renewable energy technologies (Kemp, Schot et al. 1998; Rotmans 2003; Jacobsson and Bergek 2004; Foxon, Gross et al. 2005). More specifically, Jacobsson and Bergek (2004) argue that uncertainty is blocking the development and implementation of renewable energy technologies, since it hinders the fulfilment of entrepreneurial activities (Jacobsson and Bergek 2004). This is problematic, since the emergence of a new technology cannot take place without the involvement of entrepreneurs who dare to take action under uncertainty, in pursue of a possible opportunity arising from the new technology (Hekkert, Suurs et al. 2007). In order to contribute to a better understanding of the underlying mechanisms that determine the emergence of renewable energy technologies, this article therefore aims to provide insight into the influence of uncertainty on entrepreneurial action in emerging renewable energy technologies.

In traditional entrepreneurship literature, the success or failure of entrepreneurial action is often attributed to specific individuals who have the vision, skills and risk-taking mentality needed to discover, create and exploit opportunities that lie beyond the reach of most (see Gartner 1990 for an overview). However, there is a growing awareness that the development of emerging technologies cannot be attributed to any one individual actor, but is best understood as "*both an individual and a collective act*" (Van de Ven 1993; Edquist 2001; Garud and Karnøe 2003; Jacobsson and Bergek 2004; Hekkert, Suurs et al. 2007). As Garud and Karnøe argue, "*technology entrepreneurship is a larger process that builds upon the efforts of many*" (Garud and Karnøe 2003, p. 277). According to this stream of research, entrepreneurs are not only technology developers who produce new technologies, but, for instance, also adopters (buyers and users) who offer critical inputs for the commercialization of emerging technologies (Van de Ven 1993; Garud and Karnøe 2001; Garud and Karnøe 2003). In this article, we subscribe to the idea that the development of emerging renewable energy technologies is the result of actions from multiple entrepreneurs. However, in contrast to the above scholars, we do not analyze the emerging technology from a macro- or system-level perspective but focus on specific innovation projects from the perspective of the various entrepreneurs involved. In this article, we focus on the development of biomass gasification technology by studying various innovation projects aimed to develop and implement this emerging renewable energy technology. This focus on innovation projects is useful for providing more insight into the relation between entrepreneurial action and the perception of uncertainties.

This study builds on the work of McMullen and Shepherd (2006) who argue that, in order to understand the influence of perceived uncertainty on entrepreneurial action, we are required to examine not only perceived uncertainty but also the entrepreneur's motivation. They explain that whether an entrepreneur will engage in a particular action is a decision that depends on whether the entrepreneur is motivated enough to act, given the uncertainty he or she expects to encounter in pursuit of an opportunity (McMullen and Shepherd 2006). Thus, motivation needs to outweigh perceived uncertainty in order for entrepreneurs to act. This implies that we need to analyse both perceived uncertainty as well as the balance between perceived uncertainty and motivation if we want to understand why some entrepreneurs decide to act whereas others do not.

We will make three contributions to the conceptual framework of McMullen and Shepherd (2006). First, we will break down uncertainty perceptions in different sources of uncertainty. Whereas McMullen and Shepherd (2006) analyse perceived uncertainty by looking at whether or not an entrepreneur possesses enough knowledge in order to recognize an opportunity worth pursuing, we try to specify in what domains knowledge is lacking by distinguishing between different uncertainty sources. The entrepreneurs involved in emerging technologies are not only confronted with high uncertainty about the technology itself, but also with uncertainty about other elements in the socio-institutional environment in which the new technology will be embedded; such as uncertainty about unclear user requirements or the actions of competitors (Rosenberg 1996; Afuah and Utterback 1997; Meijer, Hekkert et al. 2006). Since previous research (Meijer, Hekkert et al. 2007a) has suggested that entrepreneurs initiate different types of activities in order to deal with different sources of perceived uncertainty, we believe that identifying dominant sources of uncertainty can deliver valuable insights for entrepreneurs and policy-makers to develop strategies for better managing these uncertainties. Second, we will add a dynamic perspective. McMullen and Shepherd (2006) only focus on the initial decision of an entrepreneur to engage in entrepreneurial action. If we consider the fact that many entrepreneurial activities are stopped prematurely, then apparently an entrepreneur's decision to act is not permanent. This being true, we need to develop a more dynamic view of how perceived uncertainties and motivation, and consequently an entrepreneur's decision to act, change over time. Third, if we want to understand why some entrepreneurs decide to act whereas others do not, we need to know more about the factors that influence an entrepreneur's perception of uncertainties and motivation. Therefore, we pose the following research questions:

1. *Which sources of uncertainty are perceived to be important for the decisions of the various entrepreneurs involved in development and implementation projects of biomass gasification in the Netherlands?*
2. *How do perceived uncertainties and motivation influence entrepreneurial action in different stages*[1] *of the biomass gasification projects?*
3. *What are critical factors influencing the perceived uncertainties and the motivation of entrepreneurs in the biomass gasification projects?*

The article proceeds as follows. In Section 5.2, we discuss some relevant theories on uncertainty and introduce a typology of uncertainty sources relevant for analysing entrepreneurial action regarding emerging technologies. We apply these theoretical insights in an empirical case on biomass gasification in the Netherlands (Section 5.4). Gasification is a very efficient technology to convert biomass into electricity. Although in the Netherlands the expectations about this emerging renewable energy technology are high, the breakthrough of this technology proves difficult since many projects which were initiated by entrepreneurs to develop and implement this technology have failed (Green Balance 2004; Kwant and Knoef 2004; Van Ree, Beekes et al. 2005; Faaij 2006; Negro, Suurs et al. 2008). By analyzing several innovation projects over time and comparing them, we are able to answer our research questions. We end our article by discussing the main conclusions and policy implications (Section 5.5).

5.2 Perceived uncertainty and entrepreneurial action in emerging technologies

A useful conceptualization of uncertainty for studying uncertainty from the perspective of the entrepreneurs, originates from the organizational management literature. Within the organizational management literature, a line of research is dedicated to analyzing perceptions of uncertainty in the external environment of an organization (e.g. Duncan 1972; Milliken 1987; Boyd and Fulk 1996; Dickson and Weaver 1997; Sutcliffe and Zaheer 1998). Frances Milliken defines uncertainty as "*an individual's perceived inability to predict something accurately*" (Milliken 1987, p136). The term 'perception' refers to the process by which individuals organize and evaluate stimuli from the environment. The existence of information itself lacks meaning until an individual perceives it (Corrêa 1994). Environments are therefore neither certain nor uncertain but are simply perceived differently by various actors. Thus, this stream of research departs from the idea that uncertainty is objective by arguing that actors differ in their perception of uncertainty. Furthermore, the above-mentioned scholars conceptualize uncertainty as a multidimensional construct and, therefore, emphasize that it is important to identify the different sources of uncertainty which the actor is uncertain about (Duncan 1972; Milliken 1987; Dickson and Weaver 1997). Following these organizational management scholars, we apply a subjective perspective on uncertainty (and therefore use the term 'perceived uncertainty') and consider perceived uncertainty as comprising of different uncertainty sources.

For decisions concerning emerging technologies, an apparent source of uncertainty is technological uncertainty, since the performance of the new technology is still unclear and many alternative designs are competing for dominance (Tushman and Rosenkopf 1992; Rosenberg 1996; Anderson and Tushman 2001). However, uncertainty will not only arise about the technology itself, which still needs to be shaped, but also about the socio-institutional setting in which the emerging technology will be embedded. In this early phase, user demands are not clearly articulated and a market for the new technology still has to be created. Technology developers will perceive uncertainty about user requirements and market demand, whereas potential users will perceive uncertainty about what the new technology might have to offer (Tushman and Rosenkopf 1992; Afuah and Utterback 1997). In addition, current regulation is aligned with established technologies and does not always provide room for the introduction of new technologies (Jacobsson and Bergek 2004). This creates uncertainty about which institutional regulations and support mechanisms will emerge for the new technology (Van de Ven 1993). As a result, the actors involved in the development and implementation of emerging technologies are confronted with high uncertainties in different domains. Based on an extensive literature review and previous empirical work, which is reported in (Meijer, Hekkert et al. 2006) and (Meijer, Hekkert et al. 2007a), we propose to distinguish between the following set of uncertainty sources for analyzing perceptions of uncertainties concerning the development and implementation of emerging technologies: technological, resource, competitive, supplier, consumer and political uncertainty (see Table 5-1).

The effect of uncertainty on innovation has been the subject of many studies. A distinction can be made between studies that focus on uncertainty in relation to the development of new products and studies that analyze the effect of uncertainty on the adoption of new technologies. In the new product development literature, much attention has been paid to analyzing the effect of uncertainty on the development process and on the success of new products (e.g. Griffin and Hauser 1996; Mullins and Sutherland 1998; Souder, Sherman et al. 1998; Bstieler and Gross 2003). The aim of most of these studies is to determine which strategies (in terms of different approaches to scan potential markets, distinctive levels of R&D/market integration or different learning strategies) are most effective in reducing the uncertainties encountered in new product development. The adoption studies, in turn, have developed important insights into the optimal timing problem of adopting a new technology under uncertainty by modelling the dilemma that firms face when having to weigh the costs of adopting too soon ('sunk costs' which cannot be recovered) against the opportunity cost of waiting in anticipation of better future technologies

Table 5-1 Sources of perceived uncertainty with respect to innovation decisions.

Uncertainty source	Description
Technological uncertainty	This source includes uncertainty about the characteristics of the new technology (such as costs or performance), about the relation between the new technology and the technical infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed), and about the possibility of choosing alternative (future) technological options.
Resource uncertainty	This source includes both uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation, and uncertainty about how to organize the innovation process (e.g. in-house or external R&D, technology transfer, education of personnel). Resource uncertainty resides at the level of the individual firm, as well as at the level of the innovation system.
Competitive uncertainty	Whereas technological uncertainty includes uncertainty about competing technological options, competitive uncertainty relates to uncertainty about the behaviour of (potential or actual) competitors and the effects of this behaviour.
Supplier uncertainty	Uncertainty about the actions of suppliers (i.e. uncertainty about the reliability of the supplier), which often manifests itself as uncertainty if the supplier will live up to agreements about the timing, quality, and price of the delivery. Supplier uncertainty becomes increasingly important when the dependence on a supplier is high.
Consumer uncertainty	Uncertainty about consumers relates to uncertainty about consumers' preferences with respect to the new technology, about the compatibility of the new technology with consumers' characteristics[2], and, in general, uncertainty about the long-term development of the demand over time.
Political uncertainty	Political uncertainty comprises uncertainty about governmental behaviour, regimes, and policies. Not only changes in policy, but also ambiguity in interpretation of current policy or a lack of policy can lead to uncertainty. Another important cause for political uncertainty is unpredictability of governmental behaviour.

(e.g. Mamer and McCardle 1987; Saha, Love et al. 1994; Farzin, Huisman et al. 1998; Marra, Pannell et al. 2003; Doraszelski 2004). One of the outcomes of these studies, is that, even though new technologies might be superior to the established technologies, firms are very cautious to adopt new technologies because of the various uncertainties they perceive (Farzin, Huisman et al. 1998).

However, these studies do not provide sufficient insight to understand the role of uncertainties in emerging renewable energy technologies. Namely, a shortcoming of these studies is that they mainly focus on *individual* firms that are either developing or adopting a new technological product. Before an emerging energy technology has become so mature that it can be sold as a 'turn-key' energy plant, the technology very often enters the market as a first-of-a-kind product, consisting of different components that were never before integrated (Williams and Edge 1996). In many cases, the technology needs to be adapted to the specific circumstances at the location of application (such as the available feedstock). In this early phase of development, both knowledge of the technology and knowledge of the adopting firm are needed to develop a successful working energy plant. The user of such a 'first-of-a-kind' energy plant, the adopter, therefore has a very influential role in the learning experiences with the emerging energy technology. As a result, in most adoption processes of emergent energy technologies there exists a very close interaction between the adopter and the technology developer (producer). Previous studies on uncertainty and innovation do not provide sufficient insight into the influence of uncertainty on innovation projects in which technology development and adoption are to a large extent intertwined. In addition, most of these studies evaluate which strategies are most effective in dealing with uncertainty (e.g. market research helps to reduce uncertainty about consumer demands, Mamer and McCardle 1987; Mullins and Sutherland 1998), but little attention is paid to providing explanations for the fact that in some cases firms decide to act entrepreneurially by engaging in the development of an emerging technology, whereas in other cases they do not. In this article, we aim to address these under-analyzed topics.

To do so, we build on a recent article by McMullen and Shepherd on entrepreneurial action and the role of uncertainty in theories of entrepreneurship in which they explain that one cannot understand the decision of entrepreneurs whether or not to act under uncertainty without taking into account the entrepreneur's motivation (McMullen and Shepherd 2006). They explain that "*entrepreneurs respond to and create change through their entrepreneurial actions, where entrepreneurial action refers to behaviour in response to a judgemental decision under uncertainty about a possible opportunity for profit*" (McMullen and Shepherd 2006, p. 134). They argue that whether an entrepreneur will engage in a particular action (e.g. engage in the development and implementation of an emerging technology) is a decision that depends on whether the entrepreneur is motivated enough to act, given the uncertainty he or she expects to encounter in pursuit of an opportunity arising from the emerging technology. (McMullen and Shepherd 2006) Thus, motivation needs to outweigh perceived uncertainty in order for entrepreneurs to act. This implies that, in order to understand the relation between entrepreneurial action and uncertainty, we are required to examine both perceived uncertainty and the balance between perceived uncertainty and motivation (see inner core of Figure 5-1).

Although the conceptual work of McMullen and Shepherd (2006) provides a useful basis for understanding the role of perceived uncertainty on entrepreneurial action, little sense is given to the underlying factors which influence an entrepreneur's perception of uncertainty and motivation to bear uncertainty. The decisions of entrepreneurs to engage in innovation projects aimed to develop and implement an emerging energy technology do not take place in a vacuum, but are influenced by the context in which these decisions are made. Factors in the internal and external project-environment can greatly affect the entrepreneur's perception of uncertainties and/or his motivation to take action. If we want to understand why some entrepreneurs decide to act whereas others do not, we need to extend the conceptual model by identifying the critical factors in the internal or external project-environment which influence the perceived uncertainties or motivation of entrepreneurs (see left-hand side of Figure 5-1).[3]

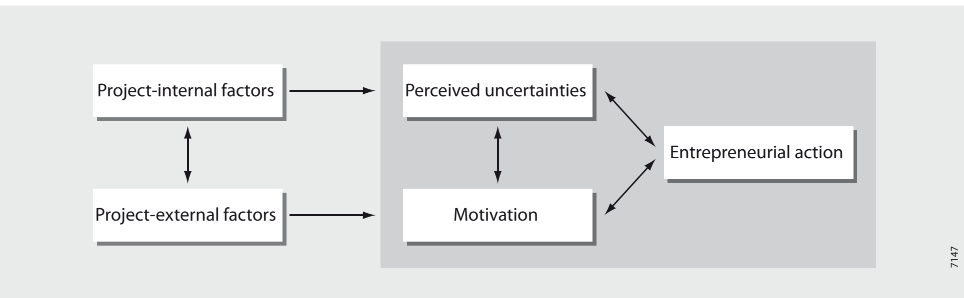

Figure 5-1 A conceptual model describing entrepreneurial action under perceived uncertainty.

Another shortcoming of the framework of McMullen and Shepherd (2006) is that it only describes the initial decision of an entrepreneur to engage in a particular action. If we consider the fact that many entrepreneurial activities are stopped prematurely, then apparently entrepreneurs do not make this judgement once but constantly reassess their decision. Perceived uncertainties and motivation will not be stable, but will evolve over time under the influence of previous actions, changes in the internal or external factors, and so on. Therefore, we claim that a dynamic analysis is needed in order to understand when and why this balance between perceived uncertainty and motivation changes.

5.3 Methodology

In this article, we apply our ideas on perceived uncertainty and entrepreneurial action to the empirical case of stand-alone biomass gasification in the Netherlands.[4] For this case study, we examined seven innovation projects aimed at the development and implementation of biomass gasification. In order to perform a dynamic analysis, we collected data on various project stages: the start-up stage, the implementation stage and the exploitation stage. The start-up stage ends when the construction of the plant starts; the implementation stage ends when the gasification plant is operational. From the total population of Dutch biomass gasification projects (including both terminated and ongoing projects, both small scale projects of 1-5 MW_e and large-scale projects of 20 MW_e or more), we studied all four projects that have reached the implementation or exploitation stage as well as three projects that were abandoned in the start-up stage.[5] An overview of the projects included in our case study is given in Figure 5-2.

Data was collected by conducting 16 interviews. We mostly interviewed technology developers (suppliers of gasification technology) and adopters (buyers and users of gasification technology,

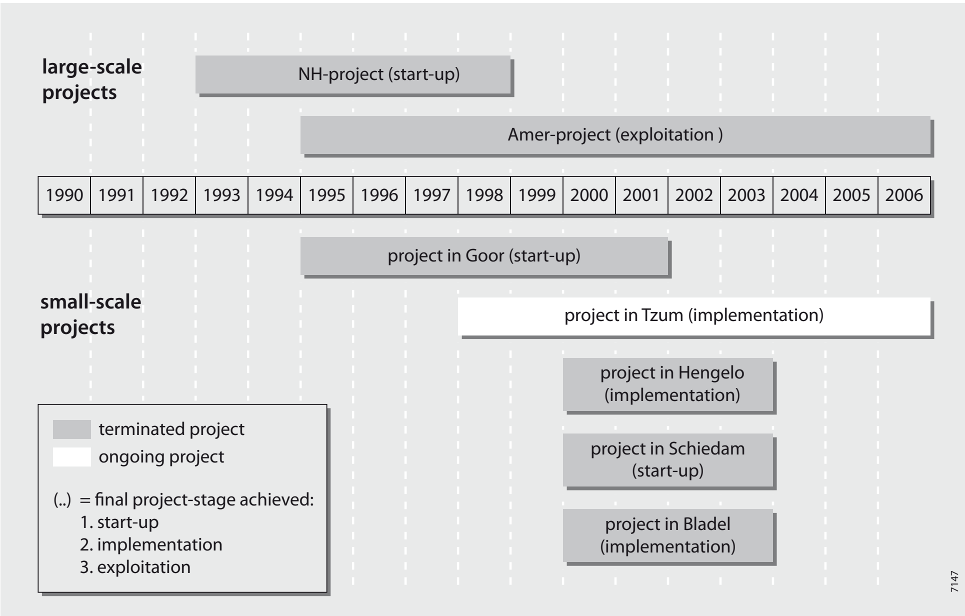

Figure 5-2 Timeline of studied biomass gasification projects.

such as energy companies, farmers or waste processing companies), as these parties fulfilled the role of entrepreneur in the biomass gasification projects.[6] We aimed at conducting more than one interview for each project, in order to include differences in perceptions between the various entrepreneurs involved and to triangulate the data of the different interviews. In addition to the interviews with the entrepreneurs, we conducted some interviews with researchers and governmental authorities who have a broad overview of the developments in the Netherlands.

The advantage of interviews is that information can be gathered on perceptions and strategies of actors, which would be difficult to obtain from other sources. However, the drawback of interviews is that selective or biased answers can be given. This is especially the case for interviews about historical events (such as projects that took place several years ago). In order to avoid this drawback as much as possible and improve the reliability and validity of the data, we combined the information from the interviews with information from other data sources (data triangulation). Prior to the interview, we studied various types of documents (policy documents, scientific articles, project reports, professional journals and newspaper articles) to identify the key events in which the interviewee had been involved. During the first part of the interviews, we used these key events in order to help the interviewee recalling specific situations and in that way reconstruct the project's storyline. Using this storyline, the second part of the interviews focused on identifying the entrepreneurs' motivations, perceptions of uncertainties, decisions on whether or not to continue and the actions that followed from these decisions for different stages of the project. Perceptions of uncertainty were identified by using open questions in which the interviewees had to describe their perceptions (independent of our typology of uncertainty sources) as well as closed questions in which the interviewees had to rank each of the uncertainty sources according to the level of uncertainty and the relative importance in relation to the other uncertainty sources. After the interviews, we used the various types of documents to verify and complete the data from the interviews.

5.4 Biomass gasification in the Netherlands

Producing energy out of biomass is seen as one of the key options to mitigate greenhouse gas emissions and substitute fossil fuels (Faaij 2006). Biomass materials that can be used for energy production are very diverse, ranging from food crops and forest products (such as wood thinning or straw) to waste streams as demolition wood or chicken manure. Gasification is a thermo-chemical process technology that converts biomass into a combustible gas (called 'producer gas' or 'syngas') (Den Uil, Van Ree et al. 2004).[7] The produced gas (consisting mainly of CO and H_2) can be burned for heat or steam supply, or it can be used in secondary conversion technologies such as gas turbines and engines for producing electricity or mechanical work.[8] The advantage of gasification, is that much higher electrical efficiencies can be reached (35-40%) compared to combustion power plants (25-30%) (Williams and Larson 1996; Faaij, van Ree et al. 1997). However, gasification is technologically much more complex. Although this emerging technology can make a substantial contribution to the achievement of a renewable energy system, realization of biomass gasification projects often proves difficult and only a few projects in Europe have achieved a commercial status (Kwant and Knoef 2004; Faaij 2006). In the Netherlands, entrepreneurs have initiated numerous activities to develop and implement this technology, but many of these activities have been abandoned (Green Balance 2004; Van Ree, Beekes et al. 2005; Negro, Suurs et al. 2008). Below, we analyse what role perceived uncertainties have played in this.

Table 5-2 General overview of the uncertainties that are perceived as dominant.

Uncertainty source	Examples mentiond by interviewees (n=12)	Number of interviewees	% of interviewees
Technological	uncertainty about the technology itself	11	92
	uncertainty about the choice between different technological alternatives	2	17
	number of other examples mentioned by only 1 interviewee	0	0
	Total number of examples for technological uncertainty	**13**	
Political	uncertainty about the licensing procedure and emission regulation	8	67
	uncertainty about financial instruments (REB, MEP)	7	58
	number of other examples mentioned by only 1 interviewee	6	50
	Total number of examples for political uncertainty	**21**	
Resource	uncertainty about biomass resources	5	42
	uncertainty about financial resources	5	42
	number of other examples mentioned by only 1 interviewee	2	17
	Total number of examples for resource uncertainty	**12**	
Supplier	uncertainty about the reliability of technology-suppliers	1	8
	uncertainty about the reliability of biomass-suppliers	1	8
	number of other examples mentioned by only 1 interviewee	0	0
	Total number of examples for supplier uncertainty	**2**	
Competitive	number of examples mentioned by only 1 interviewee	0	0
	Total number of examples for competitive uncertainty	**0**	
Consumer	uncertainty about the consumers of the produced electricity	2	17
	number of other examples mentioned by only 1 interviewee	0	0
	Total number of examples for consumer uncertainty	**2**	

5.4.1 The dominant uncertainty sources

In Section 5.2, we introduced a typology of uncertainty sources with respect to innovation decisions of entrepreneurs. In order to analyze what uncertainty sources played a dominant role in the development and implementation of biomass gasification, we asked the interviewees which uncertainties they perceived as dominant for their decisions regarding biomass gasification and classified their answers according to our typology of uncertainty sources (see Table 5-2).[9] As Table 5-2 shows, technological uncertainty, political uncertainty and resource uncertainty were mentioned far more often than the other uncertainty sources and therefore can be considered most important in innovation decisions.

Arguments for the importance of uncertainty about the technology itself were the lack of previous experiences with the technology that created uncertainty about the performance of biomass gasification plants. Also the time needed to make the technology actually work was often mentioned to cause uncertainty.

The first argument why political uncertainty was so important was related to uncertainty about the licensing procedure and emission regulation. In order to build a biomass gasification plant, a license needs to be obtained in which specific rules (including emission norms) are laid down. In the Netherlands, the licensing procedure of bio-energy projects is very complex and ambiguous, takes very long and offers many opportunities for neighbouring people and environmentalists to object to the license (Van Ree, Gerlagh et al. 2000; Lindeman 2004; Gerlagh and Lammers 2006). As a result, the interviewees perceived great uncertainty about the duration and outcome of the licensing procedure since delay of the procedure or imposition of strict emission rules can have serious consequences for the profitability of a project. The second argument for the importance of political uncertainty was that the majority of the interviewees (58%) perceived uncertainty about the financial instruments for renewable energy in general. The financial subsidy that entrepreneurs received from the government for the production of renewable electricity has been forming an important incentive for entrepreneurs to initiate biomass gasification projects (Kwast 2006; Van Dongen 2006). However, the financial instruments of the Dutch government changed frequently and often unexpectedly over the past years. In 2003, a year later than the government initially announced, the fiscal support for renewable electricity (i.e. renewable electricity was exempted from the national energy tax, REB[10]) was replaced by the non-fiscal MEP-levy[11] that subsidizes the production of renewable electricity in the Netherlands (Kwant and Knoef 2004). In subsequent years, the Dutch government has implemented several adjustments to the MEP-instrument, which were not announced beforehand. As a result, the uncertainty that entrepreneurs perceive about changes in the financial instruments of the Dutch government, has been one of the most important aspects hindering the development and implementation of biomass gasification (Green Balance 2004; Gerlagh and Lammers 2006). The frequent and often unexpected changes to the financial instruments in the past not only resulted in perceived uncertainty about future changes to these instruments, but also about the reliability of the Dutch government in general.

Arguments for the importance of resource uncertainty were first of all related to the market for biomass. This market is relatively new and unstable, and since the demand for biomass (especially wood) has been exceeding the supply, the entrepreneurs perceived uncertainty about the availability, quality and price of biomass (Gerlagh and Lammers 2006; Schouwenberg 2006). In addition, the entrepreneurs were uncertain about financial resources. Due to the early phase of development, it is uncertain if and when the costs of an investment in biomass gasification can be recovered. The interviewees perceived uncertainty about the mobilization of financial resources both within the firm and external to the firm (from banks or other investors).

Thus, the results from Table 5-2 show that perceived uncertainty is not a one-dimensional concept, but that major sources of perceived uncertainty can be identified. For biomass gasification, the dominant sources of perceived uncertainty influencing entrepreneurial decision-making are technological, political and resource uncertainty. Since these three uncertainty sources are mentioned far more often than the other uncertainty sources, the results of Table 5-2 display a rather robust view. However, if we look back at the timeline of projects in Figure 5-2, this static analysis of uncertainty sources does not explain why some entrepreneurs decide to terminate their innovation projects whereas others continue. Therefore, we need to zoom in on the dynamics of the innovation projects.

5.4.2 Dynamic project analysis

In this section, we describe seven projects aimed to develop and implement biomass gasification in the Netherlands (see Figure 5-2). Since biomass gasification technology is not yet so mature that it can be bought 'from the shelf', all these projects can be classified as 'first-of-a-kind' projects in which technology development and adoption are to a large extent intertwined. For each project, we analyze how the entrepreneurs' perceptions of uncertainties, their motivations to engage in the innovation project and their decisions whether or not to act evolve over time. We not only describe the decisions of entrepreneurs, but also the actions that follow from these decisions. Namely, the actions that entrepreneurs undertake can subsequently lead to changes in perceived uncertainties or motivation. Furthermore, we look for internal and external factors in the project-environment influencing entrepreneurs' perceived uncertainties and motivations. We classified the projects according to the final stage achieved (start-up, implementation, exploitation).[12]

The start-up stage

- *NH-project*

In 1993, the Province[13] of North-Holland, together with the local energy companies PEN and UNA[14], the SEP[15] and ECN[16] announced to build the first large-scale biomass gasification plant in the Netherlands. The Province of North-Holland initiated and coordinated the project, driven by their ambition to provide an energy supply system that was affordable, reliable and sustainable (De Boer 2005; Daey Ouwens 2005a). At the start of the project, the entrepreneurs involved perceived uncertainty about the availability and price of biomass and about the technology, since biomass gasification was not yet a proven technology and the project members differed in opinion about which technological configuration was best and which technology supplier to select (Stuurgroep project Biomassavergassing Noord-Holland 1999; De Boer 2005; Daey Ouwens 2005a; Van Dongen 2006). Different perceptions of uncertainties by the project partners led to cooperation and coordination problems in the project consortium. Failed attempts to cooperate with the local waste processing company delayed the project even more (De Boer 2005; Daey Ouwens 2005a). Meanwhile, the institutional context in which the project was taking place was changing drastically due to the liberalization of the Dutch energy market (which was initiated in 1998). One of the results of the liberalization was that the energy companies became competitors and no longer cooperated in realization of high-risk environmental-friendly projects. Instead, their attention shifted towards lowering production costs and making low-risk investments in other domains than sustainable energy R&D (Raven 2006). Because the start-up stage was taking longer than expected, these changes in the institutional context (an 'external factor', see Figure 5-2) started to interfere with the project. While the final investment decision was still not made, the energy companies involved became increasingly reluctant to invest in such a high-risk project (De Boer 2005; Daey Ouwens 2005a; Van Dongen 2006). Since the Province could not undertake the project without the involvement of the energy companies (being the adopters of the technology), this posed a serious threat to the project (De Boer 2005; Daey Ouwens 2005a). In 1998, the entrepreneurs collectively decided to abort their plans (Stuurgroep project Biomassavergassing Noord-Holland 1999). As the entrepreneurs involved themselves indicated, this decision was influenced by a combination of perceived uncertainties and diminished motivation (De Boer 2005; Daey Ouwens 2005a; Van Dongen 2006). The many delays of the project, and the changes in the institutional setting which occurred during this long time period, reduced the motivation of the entrepreneurs. Adding to this explanation was that the actor constitution (an 'internal factor', see Figure 5-2) had been too complex as the various entrepreneurs involved were too diverse in order to collectively undertake this project. The involvement of multiple entrepreneurs in a project increases the chance that the perceptions of uncertainty and the motivation to engage in the project diverge among the various entrepreneurs involved. Since the lack of a common understanding can hamper fruitful cooperation in multi-actor projects (e.g. Koppenjan 2005), diverging perceptions and motivations increases the risk of project abortion.

- *Project in Goor*

In 1995, technology developer BTG, energy company Edon and wood processing company Bruins & Kwast jointly initiated the plan to implement a small-scale gasification plant in Goor. Edon and BTG had both been involved in an EU-sponsored R&D project on fixed-bed gasification of biomass which had been evaluated positively, and therefore decided to continue their activities with this technology by starting an implementation project (Knoef 2006). Wood processing company Bruins & Kwast decided to engage in the project because of the opportunities that this high-efficient technology had to offer for the conversion of wood residues into energy (Kwast 2006). At the start of the project, the main sources of perceived uncertainty were technological uncertainty and political uncertainty (uncertainty about the licensing procedure) (Knoef 2006; Kwast 2006). Because the project team thought that these perceived uncertainties could be reduced, these uncertainties did not form a barrier (Knoef 2006). However, just as in the NH-project, changes in the institutional context interfered with the project. Due to the liberalization of the energy market, the constitution of actors involved in the project changed as energy company Edon was taken over by Essent. As a result, the project proposal had to be re-approved by Essent's board of directors. However, because Essent did not have much faith in small-scale gasification, Essent's motivation to engage in the project did not outweigh the perceived uncertainties. As a result, the project was cancelled (Green Balance 2004; Knoef 2006; Kwast 2006).

Like in the NH-project, this project shows that institutional change (an 'external' factor) can negatively influence the decision of entrepreneurs to engage in innovation projects. Furthermore, this project shows that the entry of a new player (e.g. change of the actor-constitution; an 'internal' factor) can have a major impact on the continuation of an innovation project as new players might be less willing to bear perceived uncertainties than the actors who initiated the project. This is in line with the findings of Van de Ven and colleagues (1999), which show that changes in management can have disruptive effects on innovation projects that received a lot of support from the previous management team.

- *Project in Schiedam*

In 2000, technology developer BTG and energy company ONS decided to install a biomass gasification plant at the site of ONS in Schiedam. For BTG, the project offered the opportunity to install two gasifier-units, which had already been built and tested, in a real-life situation so as to learn how the technology would perform. Energy company ONS was mainly interested in the implementation of these biomass gasifier-units in order to produce renewable electricity. (Tijmensen and De Vos 2005; Knoef 2006) From the start of the project, technological uncertainty, resource uncertainty (i.e. uncertainty about knowledge, financial resources and biomass resources) and political uncertainty were perceived to be high (Knoef 2006). Since two different gasifier-units would have to be coupled together, technological uncertainty was higher compared to other small-scale gasification projects. Despite the high perceived uncertainties, the project team was fully committed to the project since they believed in the opportunity of implementing the available gasifier-units (Knoef 2006). After years of preparation, the project team presented the project proposal to the board of directors of ONS. In contrast to the project team, the gasification project was but one of a set of business plans that the board of directors had to consider. The board of directors rejected the plan as they perceived the investment risks of the gasification project too high (Green Balance 2004; Knoef 2006). The project team attempted to reduce the risks by reducing the scale of the project to one gasifier-unit instead of two, which would lower the technological complexity and costs of the project. Nevertheless, the board of directors also turned down the renewed proposal and the project was terminated. Again, a collective entrepreneurial project was terminated because the adopter of the technology retreated. Similar to the project in Goor, this project showed that the involvement of a new actor (i.e. a change in the actor constitution; an 'internal factor') can lead to the termination of an innovation project. In this project, the entrepreneurs who initiated the project (the members of the project team) were overruled by top managers who were less willing to tolerate perceived uncertainties. This problem is frequently encountered in innovation projects. Van de Ven and colleagues explain it as such: "*Whereas the innovation may be the exclusive labour of love for the innovation team, it is but one of a set of interacting, often competing, business considerations for top managers and investors*" (Van de Ven, Polley et al. 1999, p. 58-59)

The implementation stage

- *Project in Bladel*

The small-scale gasification project in Bladel was initiated by a farmer, Mr Duis. For farmers, biomass gasification promised to be an attractive solution for the disposal of manure. Due to the increase in livestock and the strict manure disposal regulation, the costs for manure disposal were high. By implementing a gasification plant to convert manure into energy, manure disposal costs could be saved (Buffinga and Knoef 2001; Duis 2006). In 2000, Mr Duis contacted technology developer BTG, and the project was started. One of the first uncertainties that the entrepreneurs encountered, was uncertainty about the licensing procedure. The entrepreneurs perceived uncertainty if they would obtain a license for gasification of chicken manure, since the existing manure legislation did not provide for the application of this new technology for manure disposal (Duis 2006). In reaction to this uncertainty, Mr Duis tried to gain support from the local authorities who were responsible for the licensing procedure. After many conversations, the authorities exempted the project from the manure legislation and granted a temporarily license for a trial-period of three years. (Duis 2006) The entrepreneurs believed that this three-year period would be sufficient to develop a successful working plant and to obtain a permanent license (by showing that the operational plant would comply with the emission rules) (Knoef 2006). A second important source of perceived uncertainty was technological uncertainty, since biomass gasification was not yet a 'proven' technology (Duis 2006; Knoef 2006). However, this uncertainty did not form a barrier since both entrepreneurs were eager to make the installation work. Construction of the plant was soon started. Unfortunately, the first tests were unsuccessful and revealed several technological problems. In order to solve these problems and thereby reduce technological uncertainty, the entrepreneurs jointly worked on improving the technology by 'trial-and-error' learning (Duis 2006; Knoef 2006). Although the entrepreneurs were making progress, the entrepreneurs still perceived uncertainty about how to solve the remaining technological problems. In addition to this technological uncertainty, uncertainty arose about the reliability of the supplier of one of the technological components who delivered a poorly-working product and did not live up to the agreements (Duis 2006; Knoef 2006). When the supplier even went bankrupt, Mr Duis decided to develop the component itself (Duis 2006). Thus, in contrast to the projects that were terminated in the start-up stage, the motivation of the adopter of the technology (Mr Duis), was extremely high. Nevertheless, as a result of the unanticipated problems, the project was running out of budget and uncertainty about how to mobilize additional financial resources needed to proceed with the project increased. BTG and Mr Duis had already invested significant time and money in the project, but the installation was still not operational and the period of validity of the temporary license was coming to an end. In addition to the negative influence of the limited temporal duration (an 'internal' factor), changes in the economic conditions (i.e. an 'external factor') occurred and negatively influenced the motivation to engage in the project (Knoef 2006). Due to an outbreak of avian influenza among poultry in 2002, many Dutch farmers went out of business. As a result, the high costs for manure disposal rapidly declined and the economic incentive for undertaking the project disappeared. The entrepreneurs reconsidered their actions and decided to stop. They could have decided to continue their biomass gasification activities, but then they had to again apply for a temporary license and mobilize additional financial resources. While technological uncertainty and resource uncertainty had increased in comparison to the start of the project, the motivation to cope with these perceived uncertainties had diminished as the expected outcomes of the project were no longer feasible considering the limited time left, nor attractive under the changed economic circumstances.

- *Project in Hengelo*

In 2000, technology developer HoSt approached waste processing company Twence and wood chip supplier Bruins & Kwast in order to collectively implement a small-scale fixed-bed gasifier at the site of Twence in Hengelo. Twence and Bruins & Kwast decided to engage in the project, since both companies were interested in the opportunities that this high-efficient technology had to offer for the conversion of wood residues into energy (Kwast 2006; Rooijakkers and Dijkman 2006). The project received a temporary license for a trial-period of three years (De Kant 2006). In the start-up stage, technological uncertainty was perceived to be the most important uncertainty source. The entrepreneurs realized that the development and implementation of a successful working biomass gasification plant involved many technological uncertainties because biomass gasification was still a new and 'unproven' technology. Nevertheless, the entrepreneurs believed that they would be able to overcome technological uncertainties within the available time (De Kant 2006; Kwast 2006; Rooijakkers and Dijkman 2006). However, during the implementation stage, the entrepreneurs perceived growing technological uncertainty since technological problems were more severe than expected. After some years of experimenting, the entrepreneurs had not yet been able to develop a successful working plant and the costs of the project were running high. Thus, technological uncertainty was accompanied by perceived uncertainty about how to mobilize the additional financial resources that were needed to proceed with the project. At this point in time, the limited temporal duration of the project (a project-internal factor) started to interfere, as the validity duration of the license was coming to an end while the entrepreneurs still had not been able to reduce perceived uncertainty concerning if and how they could solve the technological problems. Similar to the project in Bladel, the limited time span that remained to turn the project into a success made the entrepreneurs involved re-evaluate their actions. Because of the increase of resource uncertainty and technological uncertainty, the entrepreneurs decided to abort the project (De Kant 2006; Kwast 2006; Rooijakkers and Dijkman 2006). For technology developer HoSt, the decision to stop was also influenced by external technological developments (an 'external factor'). HoSt could have decided to continue with the development of the technology by applying for a new license and finding new investment partners. However, due to the disappointing results of this project in comparison to the good results of HoSt's activities in the development and implementation of competing technologies (e.g. fluidized-bed gasification, combustion and digestion), HoSt's faith in the potential of fixed-bed gasification had diminished over the years (De Kant 2006). Thus, for HoSt, the decision to stop was a combination of increased perceived uncertainties and diminished motivation.

- *Project in Tzum*

The project in Tzum is currently the only ongoing biomass gasification project in the Netherlands (see Figure 5-2). Just like the project in Bladel, the small-scale gasification project at the farm of Mr Atsma in Tzum was initiated to find a solution for the high costs of manure disposal (Tijmensen and De Vos 2005; De Kant 2006; Dijkstra 2006). The project was supported by a cooperation of farmers in the north of the Netherlands.[17] Technology developer HoSt delivered the fluidized-bed gasifier.[18] From the start of the project in 1998, uncertainty about the mobilization of financial resources has been playing a dominant role. The subsidy that the project acquired from the government was insufficient to cover all the costs (Dijkstra 2006). More than once, investors decided to withdraw their proposal to finance the project due to the uncertainties they perceived about the functioning of this new technology and about the financial governmental support (MEP-instrument) (De Kant 2006; Dijkstra 2006). In addition, one of the investors went bankrupt and the farmers themselves came into financial problems due to the outbreak of the avian influenza in 2002 (an 'external factor'). As a result, the project encountered large delays and the entrepreneurs perceived great uncertainty if they would be able to mobilize the financial resources that were needed to build the gasifier (De Kant 2006; Dijkstra 2006). Despite the setbacks, the entrepreneurs hold on to their plans and searched for new investors. Their persistence had not been in vain, since energy company Eneco finally decided to supply the necessary funds to start the construction of the gasifier (De Kant 2006). In January 2006, construction work was finished and testing of the installation began. At the time of the interview (June 2006), the installation was still not fully operational. Since the budget of the project is still limited, uncertainty about the mobilization of additional financial resources remains important for the continuation of the project (De Kant 2006; Dijkstra 2006). However, in contrast to the projects in Bladel and Hengelo, expectations about the outcome of the project are still high and the entrepreneurs expect that, once the installation performs well, it will be easier to acquire additional funds to go on with the project (De Kant 2006). Besides, the barrier to abandon the project is high because the entrepreneurs have already invested a lot of time and money which would be lost if they decided to stop. As a result, the entrepreneurs are extremely motivated and continue investing in order to make good on prior investments, thereby accepting high levels of perceived uncertainties. This is a typical example of 'entrapment' or 'escalating commitment' (Brockner and Rubin 1985; Brockner 1992; Ross and Staw 1993). One of the project team members explained it as such:

"*We have made enormous investments, so if we would quit now we would lose a lot of money. There is no way back. Besides, we have good prospects for scaling-up our activities since many farmers have shown interest in the technology.*" (De Kant 2006)

Thus, the positive expectations about the outcome of the project in combination with the feeling of entrapment from past investments, motivates the entrepreneurs to continue and bear perceived uncertainties.[19]

The exploitation stage

- *Amer-project*

The Amer-project was one of the first biomass gasification projects in the Netherlands and has been the only project which has reached the exploitation stage (see Figure 5-2). In 1995, several energy companies (PNEM, NUON and EPZ) together with biomass supplier BFI launched the plan to build a large-scale gasifier nearby the existing coal-fired power plant 'Amercentrale' in order to contribute to the CO_2-emission reduction policy of the Dutch government (EPZ 1995). In this period (see Figure 5-2), the energy sector had very high expectations about biomass gasification and technological uncertainty was perceived to be low (Van Buijtenen 2006; Negro 2007). Biomass gasification would merely be a new combination of technologies that were already proven in the application of coal gasification. Shortly after the start of the project, BFI decided to withdraw from the project because it was more profitable to export the demolition wood to Scandinavia than to use it for gasification in the Amer-project. As a result of this change in actor constitution (an 'internal factor'), the remaining entrepreneurs perceived uncertainty about the availability and price of biomass and decided to put the project on hold (Duurzame Energie 1996; Energie- en Milieuspectrum 1996; Willeboer 2005). After some months, the energy companies managed to close a long-term contract with another wood supplier and the project was restarted. A German technology developer was selected to build the gasifier. Although the technology developer had never before built a gasification plant for fuels other than coal, the technology developer was very confident about its competences to develop and implement a wood-gasifier. The technology developer sold the gasification plant as a commercial unit and gave guarantees about the availability of the plant (in terms of the frequency and duration of outages due to maintenance or technological failures) (Willeboer 2005). In 1999, all contracts were signed and construction of the plant began.[20]

When commissioning activities started, many technical problems arose and stable operation of the plant was impossible (Essent Energie 2001; Willeboer 2005). Biomass gasification turned out to be more complicated than expected since the process characteristics were completely different compared to coal gasification. Several modifications were needed to solve the problems. Energy company Essent (the successor of EPZ and PNEM) realized that technological uncertainties had been heavily underestimated since the technology was far from commercially viable (Willeboer 2005). As a result of the disappointing performance of the installation and the difficulty the technology developer had to solve the technical problems, Essent not only perceived technological uncertainty but also uncertainty about the reliability of the technology developer (supplier uncertainty) (Willeboer 2005). However, since already a lot of time and money had been invested, the barrier to abandon the project was much higher than in the start-up stage (Willeboer 2005). In order to make good on prior investments, Essent became extremely motivated to continue with the project ('entrapment'). As a result, Essent was willing to bear perceived uncertainties which they would not have accepted earlier-on in the project when investments were still modest. To solve the technical problems, Essent became actively involved in the technology development process. In this way, Essent was able to gain technical knowledge and hands-on experience and thereby to reduce technological uncertainty. This knowledge-base, in turn, enabled Essent to take over the maintenance and operation of the plant and terminate the contract with the German technology developer, thereby eliminating supplier uncertainty. In 2005, the gasification plant was finally operational and the project entered the exploitation stage.

This project is probably the clearest example that the time needed for the development and implementation of biomass gasification is often underestimated. Instead of four months, seven years were needed to make the installation function properly! However, in contrast to the projects in Bladel and Hengelo, the setbacks that occurred not only radically changed the perceived uncertainties and expectations in this project, but also in the sector at large. Because the Amer-project was the first large-scale biomass gasification project in the Netherlands that had reached the implementation stage, the project had a large exposure. The severe problems of the Amer-project, in combination with the bad experience from unsuccessful implementation projects abroad, made people in the whole sector realize that expectations had been overly optimistic and uncertainties heavily underestimated (Van Buijtenen 2006; Van der Drift 2006). Uncertainty about the performance of biomass gasification technology increased and actors became more reluctant to invest in large-scale biomass gasification projects (Van Dongen 2006; Negro 2007). To illustrate this, we point out the fact that the diminished faith in biomass gasification technology was one of the main reasons for energy company Nuon to abort the plan to build a biomass gasification installation nearby one of their power plants ('Hemweg-8 centrale') (Van Dongen 2006). Moreover, banks became unwilling to issue loans for such high-risk projects in biomass gasification (Van Dongen 2006).

Because of the disappointing results, it is even more surprising that the Amer-project was not terminated during the implementation stage. This underlines the perseverance and commitment of the adopter to make the project successful and to cope with perceived uncertainties. Unfortunately, uncertainties did not disappear when the Amer-project reached the exploitation stage. Even though technological uncertainty had finally decreased, there was an increase in political uncertainty. The reason for this was that the government had announced a new emission law (i.e. institutional change, an 'external factor'). The effect of this new law was that not only the gasifier itself, but also the coal-fired power plant in which the syngas was co-combusted would fall into the category of waste-disposal companies. Since waste-disposal companies had to comply with very strict emission rules, the biomass gasification project would no longer be economically feasible under the new emission law (Willeboer 2005; Schouwenberg 2006). Thus, the new emission law made no provision for an exceptional case like the Amer-project.[21] Essent approached the government in order to raise awareness for the problem and to request a solution. The government promised to solve the problem by exempting the Amer-project from the emission law. However, one and a half years later, Essent was still waiting for the official exemption and, as a result, perceived ever growing uncertainty if the government would live up to its promise (Willeboer 2005). When, in December 2005, the new law came into force, the Amer-project still had not received an exemption. Since Essent still had hope while uncertainty about the exemption continued to exist, the introduction of the new law put an end to both uncertainty and hope. After all the efforts that had been made to make the gasification plant operational, the gasifier was shut-down. (Schouwenberg 2006; Van den Brand 2006) Governmental policy had changed from being an incentive to start the project into the death-blow that stopped the project.

Thus, the termination of this project was not the result of perceived uncertainty, but of the disruptive effect of the new law on the entrepreneur's motivation to continue biomass gasification activities. Nevertheless, this incident has led to an increase of perceived uncertainty in another manner: since the government had not been able to keep its promise about the exemption, Essent perceives uncertainty about the reliability of the government as an important barrier to new investments in innovative renewable energy projects (Willeboer 2005; Schouwenberg 2006).[22]

5.4.3 Towards a dynamic view of entrepreneurial action under perceived uncertainties

Analyzing the above project descriptions helps us to gain a deeper understanding of the complex relation between perceived uncertainties, motivation and the decision of entrepreneurs to take action. First of all, the project descriptions supported the argument of McMullen and Shepherd (2006), put forward in Section 5.2, that whether or not an entrepreneur decides to act is not only dependent on the perceived uncertainties, but also on the entrepreneur's motivation. In all projects we observed that the decision to initiate the project was based on the recognition of an opportunity arising from the emerging technology (e.g. technology developers discovered opportunities for making profit out of selling biomass gasification plants, whereas adopters of the technology saw opportunities for making profit by selling the renewable energy produced with biomass gasification). These positive expectations about the potential rewards of the project initially formed a strong motivation for the entrepreneurs to bear perceived uncertainties.

Another result of the dynamic project analysis is that it revealed that the decision of entrepreneurs to act is not a permanent decision, but rather one that is constantly reassessed. The project descriptions clearly showed that perceived uncertainties and motivation are not stable, but change over time. At the start of the biomass gasification projects, we noticed that motivation of the entrepreneurs was high enough to counter perceived uncertainties. However, in most of the projects, this initial balance between motivation and perceived uncertainties changed over time. Entrepreneurs abandoned their projects because motivation had declined and/or perceived uncertainties had increased. These changes in motivation and perceived uncertainties can have several causes. Below, we describe how various factors in the internal and external project-environment may influence the perceived uncertainties and motivation of entrepreneurs.

Critical factors in the internal and external project-environment

Our empirical results demonstrated that the perception of uncertainty and motivation are influenced by various project-internal factors (see Figure 5-3). One of the project-internal factors that played an important role in the biomass gasification projects, was the constitution of actors involved in the projects. Since actors have different frames of reference, motives to engage in the project, experiences and skills, they will also differ in their perception of uncertainty and reaction to uncertainty. As the NH-project showed, the involvement of multiple entrepreneurs in a project increases the chance that the perceptions of uncertainty and the motivation to engage in the project diverge among the various entrepreneurs involved. Since the lack of a common understanding can hamper fruitful cooperation in multi-actor projects (e.g. Koppenjan 2005),

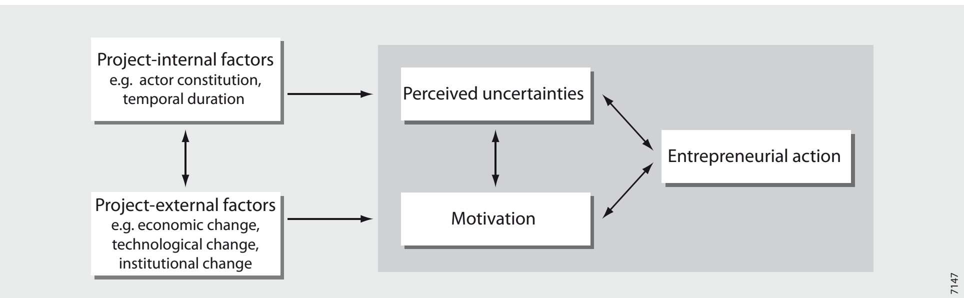

Figure 5-3 Conceptual model relating entrepreneurial action to perceived uncertainties, motivation and various internal and external factors.

diverging perceptions and motivations increases the risk of project abortion. Furthermore, the constitution of actors involved in an innovation project is not necessarily stable (Garud and Karnøe 2003; Koppenjan and Klijn 2004). Actors can enter or exit the project and the roles that actors play within the project can alter over time. The projects in Goor and Schiedam showed that the entrance of a new actor who is less willing to bear perceived uncertainties can have serious consequences for the continuation of an innovation project.

Another example of a project-internal factor that played an influential role in the biomass gasification projects was the temporal duration of the project. The time and financial resources that are available to turn an innovation project into a success are limited. The projects in Bladel and Hengelo showed that this is often underestimated. The projects in Bladel and Hengelo both received a temporary license for a period of three years, which was supposed to be sufficient to develop a successful-working plant. Due to the limited time scale of the project, the entrepreneurs were forced to re-evaluate their actions when the validity period of the license was coming to an end. The entrepreneurs realized that they were unable to reduce uncertainty about how to solve the remaining technological problems and uncertainty about how to mobilize additional financial resources within the limited time they had still left. They decided to abandon their projects instead of trying to obtain a new license in order to continue their biomass gasification activities. Thus, the limited temporal duration of the project negatively reinforced the perceived uncertainties and motivation of the entrepreneurs to continue with the project. The Amer-project, on the contrary, did not have a limited time scale. Although the Amer-project encountered just as much technological problems as the projects in Bladel and Hengelo, the entrepreneur of the Amer-project managed to develop a successful-working plant after seven difficult years. If the entrepreneur would have faced a hard deadline within this seven-year period, he might as well have decided to stop. Since there was no deadline, the entrepreneur was able to continue experimenting with the technology and thereby to reduce technological uncertainty. However, the temporal duration of a project can also play a role in projects which do not encounter a hard deadline. For example, in the NH-project, the long delays led to a loss of 'momentum' and to declining motivation of the entrepreneurs involved.

Apart from project-internal factors, the project descriptions showed that several factors in the external environment of a project influence the perceptions of uncertainties and motivation of entrepreneurs (see Figure 5-3). For example, economic change (e.g. changes in the market prices) can influence the expected profits of the project. This was clearly visible in the project in Bladel, which was initiated to avoid high manure disposal costs. Due to an outbreak of avian influenza, the manure disposal costs decreased and therefore the expected savings which the project would yield diminished. Since the economic incentive to engage in the project had vanished, the motivation of the entrepreneur decreased.

The project descriptions furthermore showed that external technological developments can greatly affect the entrepreneurs' motivation and perceptions of uncertainty. In the Hengelo-project, we noticed that perceived technological uncertainty increased and expectations about the outcome of the biomass gasification project (and thereby the motivation to engage in the project) decreased due to successful developments of competitive technologies. The sector-wide effects of the technological failures in the Amer-project illustrated that not only developments of competitive technologies, but also developments of competitive projects with identical technologies can influence how entrepreneurs perceive and respond to uncertainties. Due to the failures of the Amer-project, entrepreneurs of other biomass gasification projects became more uncertain about the technology and, in several cases, even abandoned their activities.

Another example of an external factor which we observed in the biomass gasification projects, was institutional change. Institutions (such as regulation, standards and so on) guide actors' perceptions and actions (Edquist 1997; Geels 2004). Institutional change can therefore greatly influence how entrepreneurs perceive and respond to uncertainties. In the empirical case, the NH-project and the project in Goor were influenced by the liberalisation of the energy market. The liberalization drastically affected the goals and management strategies of the energy companies, since energy companies became competitors and no longer cooperated in the realization of high-risk environmental-friendly projects (Raven 2006). As a result of this institutional change, the incentive for energy companies to engage in a biomass gasification project and the willingness to bear perceived uncertainties had diminished.

In a similar manner, various other internal and external factors may influence the perception of uncertainties and motivation of the entrepreneurs and, consequently, the decision whether or not to act. What makes it even more complex, is that different interaction patterns may occur between the variables in the model (see Figure 5-3).

Interaction patterns

When analyzing the biomass gasification, we observed that many of the abandoned projects can be characterized by the occurrence of negative interaction patterns, where internal factors, external factors and perceived uncertainties interact and reinforce each other in a negative way. One of the negative interaction patterns observed in the project descriptions, was the interaction between temporal duration (a project-internal factor) and institutional change (a project-external factor). The long duration of a project increases the chance that changes in external factors occur. For instance, if the NH-project would not have been delayed (like in the Amer-project, which started approximately at the same time), the investment decision would already have been made before the liberalisation of the energy market started to interfere with the investment decisions of the energy companies. In a similar manner, we observed that changes in external factors can reinforce changes in internal factors. To illustrate, in the project in Goor the liberalisation of the energy market (external factor) resulted in a change in the actor constitution (internal factor), which in turn resulted in re-evaluation and termination of the project.

Apart from interactions between the internal and external factors, different sources of perceived uncertainty can reinforce each other in a negative manner. For example, several investors decided to withdraw their proposal to finance the project in Tzum due to the uncertainties they perceived about the performance of this emerging energy technology and about the financial support from the government. As a result, entrepreneurs became uncertain about the mobilization of financial resources and the project was seriously delayed. This negative interaction pattern between technological uncertainty and resource uncertainty was also visible in the sector at large. Due to the poor results of the Amer-project and various projects abroad, perceived uncertainty about the performance of biomass gasification technology increased in the sector as a whole. This technological uncertainty made banks reluctant to invest in biomass gasification projects. As a result, entrepreneurs became uncertain about the mobilization of financial resources and decided to postpone or cancel their projects. Thus, negative technological developments external to the project may lead to an increase of perceived technological uncertainty, which in turn may lead to an increase of perceived uncertainty about resources and thereby to a slowing down or termination of the innovation project. In the same manner, other negative interaction patterns can develop and hamper entrepreneurial action.

Luckily, not all interaction patterns have a negative influence on the continuation of entrepreneurial action. The project descriptions illustrated that the decision whether or not to continue entrepreneurial action can be positively influenced by previous actions of the entrepreneur. The project descriptions showed that, if an entrepreneur is motivated to take action under perceived uncertainties, the entrepreneur will initiate all sorts of activities in order to reduce the major sources of perceived uncertainty. For example, in the Bladel-project, the entrepreneur initiated a dialogue with the local governmental authorities who were responsible for the licensing procedure in order to gain support for the project. By involving governmental authorities, the entrepreneur managed to reduce political uncertainty. In reaction to uncertainty about the mobilization of biomass resources (Amer-project) or financial resources (project in Tzum), we noticed that entrepreneurs aimed at cooperation with biomass suppliers and, respectively, external investment partners. In both the Bladel-project and the Amer-project, we observed that the entrepreneurs actively engaged in technology development activities to build up technological know-how and become independent of technology suppliers. Thus, experimenting with the technology helped to reduce technological uncertainty and uncertainty about the reliability of technology suppliers. As was shown in the Amer-project, this reduction of perceived uncertainties, in turn, may stimulate the entrepreneur to continue entrepreneurial action. Thus, if entrepreneurial action results in a reduction of perceived uncertainties, which reinforces the entrepreneur's motivation and, finally, leads to continuation of entrepreneurial action, we speak of a positive interaction pattern.

The type of interaction patterns that arise are highly context-specific and can differ in each stage of the project. For instance, in the start-up stage of the Amer-project, the entrepreneur was not motivated enough to cope with uncertainty about the availability and price of biomass resources and decided to put the project on-hold. In this stage of the project, investments were still modest and the consequences of delaying or terminating the project were small. However, as investments mounted during the implementation stage, so did the barrier to abandon the project. To make good on prior investments, the entrepreneur was extremely motivated to turn the project into a success. As a result of this 'entrapment' situation, the entrepreneur was far more willing to cope with perceived uncertainties than in the start-up stage. Instead of deciding to delay or stop the project, the entrepreneur decided to initiate all sorts of activities to reduce the major sources of uncertainty. A positive interaction pattern of continued entrepreneurial action and decreasing perceived uncertainties was built up. This positive interaction pattern abruptly ended in the exploitation stage due to the negative influence of an external factor (the introduction of a new emission law).

Thus, the effect that perceived uncertainties have on entrepreneurial action is complicated by the large diversity of internal and external factors and the complex interdependencies between the various variables in the conceptual model (see Figure 5-3). A dynamic analysis which aims at identifying these internal and external factors and analysing the different interaction patterns is needed in order to better understand why and how perceived uncertainties, motivation and the decision of whether or not to act evolve over time.

5.5 Conclusions and policy implications

The aim of this article was to gain a deeper understanding of the role of perceived uncertainties in innovation projects aimed to develop and implement emerging renewable energy technologies. Previous researchers have often argued that the emergence of a new technology is inherently uncertain and that this uncertainty can hinder entrepreneurial action. In this article, we wanted to take this argument a step further by identifying the major sources of perceived uncertainty and analyzing how perceived uncertainty influence entrepreneurial action in different stages of an innovation project. From the empirical case on the development and implementation of biomass gasification in the Netherlands, we conclude that the dominant uncertainty sources influencing entrepreneurial decision-making in this early phase of technological development are technological, political and resource uncertainty.

Furthermore, our empirical analysis supports the argument of McMullen and Shepherd (2006) that the decision of an entrepreneur whether or not to engage in a particular action is dependent on the balance between perceived uncertainty and motivation. Entrepreneurs will decide to act only if they are motivated enough, given the uncertainty they expect to encounter in pursuit of an opportunity. However, we believe that the work of McMullen and Shepherd (2006) has some important limitations in that it only focuses on the initial decision of entrepreneurs to undertake a particular action and does not provide explanations for the fact that many innovation projects are abandoned prematurely. By performing a dynamic analysis, we were able to examine how perceived uncertainties and motivation change over time and how these changes affect the decision of entrepreneurs whether or not to continue their actions. This dynamic analysis showed that many biomass gasification projects have been abandoned before ever reaching the exploitation stage because perceived uncertainties increased over time while motivation decreased. Such changes in perceived uncertainties and motivation are influenced by various factors in the project's internal environment, such as changes in the actor constitution or the temporal duration of the project, and factors in the external environment of the project, like economic change, institutional change or technological developments external to the project. By showing how various negative and positive interaction patterns can occur between these internal and external factors and the entrepreneurs' perceived uncertainties and motivation, we provide a deeper insight into the underlying dynamics of innovation projects.

Given the increasing interest in understanding and steering entrepreneurial activities within sustainable technology development (e.g. Elzen, Geels et al. 2004; Jacobsson and Bergek 2004; Elzen and Wieczorek 2005; Raven 2006; Negro 2007), we believe that both scholars and policy-makers may benefit from this more dynamic perspective on the role of perceived uncertainties in entrepreneurial action. The conceptual framework that we applied in our empirical case, provides policy-makers three different options in order to reduce the negative consequences of perceived uncertainties on entrepreneurial action: policy can directly address the sources of uncertainty, policy can influence the motivation of the entrepreneurs, and policy can aim at decreasing the negative influence of factors in the project's environment. Using the empirical case on biomass gasification as an example, the following policy recommendations can be made. First of all, policy instruments can be aimed at directly reducing perceived uncertainties. Although some of the uncertainty sources (such as technological uncertainty or supplier uncertainty) lie beyond the direct control of policy-makers, policy-makers play an important role in reducing political uncertainty. Since our empirical analysis showed that political uncertainty is one of the major sources of uncertainty for the entrepreneurs involved in biomass gasification projects, reducing this uncertainty can form an important stimulus for entrepreneurial action. With respect to biomass gasification, the main issues are to reduce the ambiguity and complexity in the emission regulation concerning the license of bio-energy plants[23] and to reduce uncertainty about future changes to the financial instruments. Second, policy instruments can be aimed at increasing the motivation of entrepreneurs to engage in biomass gasification projects. As we described in the empirical section, the governmental subsidy that entrepreneurs receive for producing renewable electricity has formed an important incentive to engage in bio-energy projects. However, the effectiveness of these financial instruments in terms of increasing the motivation of entrepreneurs is counteracted by the uncertainty which entrepreneurs perceive with respect to the frequent and unexpected changes to these instruments. Third, policy instruments can be aimed at protecting first-of-a-kind projects like the biomass gasification projects from the negative influences of factors in the project's environment. With respect to the biomass gasification projects, one of the ways for policy-makers to do this is to grant a first-of-a-kind project a permanent license instead of a temporary license for a limited trial-period. By preventing that the limited validity duration of licenses becomes a barrier, entrepreneurs have more time to learn how best to deal with the perceived uncertainties they encounter in the development and implementation of emerging technologies. Another way to help entrepreneurs of these first-of-a-kind projects is to provide risk capital. As was illustrated in the case study, entrepreneurs often have trouble mobilizing financial resources since banks, investors or top management are reluctant to invest in high-risk projects which aim to implement emerging technologies that are not yet 'proven'. By making more governmental funds available for these first-of-a-kind projects, the projects will become less vulnerable to the judgements of above-mentioned parties and uncertainty about the mobilization of financial resources will be reduced. In order for emerging renewable energy technologies to develop into 'proven' and widely-diffused technologies, it is essential that several of these first-of-a-kind projects manage to succeed. Therefore, policy-makers should use all the options they have in order to support entrepreneurs to cope with the large uncertainties encountered in first-of-a-kind projects, and thereby prevent so many of these projects from failing.

Notes

1 In the original article, published in Energy Policy, the term "project stage" was used. In order to prevent confusion between "technology development stage" (i.e. pre-development, take-off, acceleration and stabilization stage of a technology) and "project stage" (i.e. start-up, implementation and exploitation stage of a project), the term "project stage" has been replaced by "project stage".

2 For example, an important consumers' characteristic for energy technologies is the energy demand.

3 Note that the aim of this paper is not to analyze all factors influencing the innovation decisions of entrepreneurs, but only aim at identifying those factors that greatly affect the entrepreneur's perceived uncertainty and/or motivation. That is why the internal and external factors are located in the 'outer area' of the conceptual model (see Figure 5-1).

4 This case focuses on biomass gasification plants where only biomass is gasified; combined gasification of coal and biomass is not included.

5 We tried to include all projects that terminated in the start-up stage. However, the total number of projects that were abandoned in the start-up stage is not exactly known, as not all companies report on these projects. Furthermore, we were not always able to collect information on these projects, since interviewees have difficulty to recall projects that terminated quickly after the start.

6 The entrepreneurs that we refer to in this case study are firms (rather than individuals). Of these firms, we interviewed those employees who have been directly involved in the decision-making process.

7 This is achieved through the partial combustion of the biomass material in a restricted supply of air or oxygen in a high-temperature environment.

8 The producer gas cannot only be used to produce energy, but also as feedstock for chemical processes in order to produce, for example, liquid biofuels. In this article, we focus on the application of biomass gasification for energy production.

9 We asked this question in 12 of the 15 interviews.

10 REB = Regulerende EnergieBelasting (Regulating Energy Tax)

11 MEP = regeling Milieukwaliteit ElektriciteitsProductie (Environmental quality of Electricity Production)

12 For the terminated projects, the last stage achieved is the stage in which the project has been abandoned; for the ongoing projects, this is the current stage.

13 The Province is the regional level of government in the Netherlands.

14 After the liberalization of the energy market, energy companies PEN and UNA were taken over by ENW

15 The SEP was the coordinating organization of the national energy companies

16 ECN = Energy Research Centre of the Netherlands

17 To support this project, the SBNN (Stichting Biomassavergassing Noord Nederland, Foundation for Biomass gasification North-Netherlands) has been established. Besides the farmers, a cooperation of forestry managers who is interested in gasification of wood thinning, is participating in this foundation.

18 HoSt had previously stopped their activities with fixed-bed gasifiers (see description of the Hengelo-project), but continued their work on the development of fluidized-bed gasifiers.

19 A few months after the interview (October 2006), we learned that the project in Tzum has managed to enter the exploitation stage.

20 The liberalization of the Dutch energy market in 1998 did not influence the Amer-project, since the investment decision had already been made and Essent (successor of EPZ and PNEM) did not change course. (Willeboer 2005)

21 The Amer-project was an exceptional case, since the combination of a wood-gasifier and a conventional power plant did not exist elsewhere. In the Amer-project, 'non-clean' contaminated biomass (demolition wood) is converted into 'clean' syngas, which is co-combusted in the existing power plant. The license obtained in 1998 permitted this exceptional situation, but the BVA made no provision for a transformation of 'non-clean' to 'clean' fuel and only looked at the 'non-clean' input of the gasifier.

22 Essent is investigating if they can restart the Amer-project with clean biomass material, but this would mean that additional modifications have to be made to the gasifier. (Schouwenberg 2006)

23 Although the Dutch government is aware of the fact that the emission regulation and license procedure forms an important source of uncertainty and is trying to solve the problems, their activities have not yet been sufficient to remove this uncertainty.

Interlude D

The following chapter, Chapter 6, reports on the outcomes of the fourth and final empirical case. The case focuses on the development and implementation of biomass combustion, an emerging technology which has entered the acceleration phase (i.e. the phase in which a strong diffusion of the technology takes place). The case study was performed according to the same case study design as the previous case on biomass gasification, which was reported in Chapter 5 (i.e. the same interview scheme was used for collecting data and the same conceptual model for analyzing the data). As the biomass gasification case demonstrated that interactions between different types of uncertainties and various factors in the project environment largely influence the decision of entrepreneurs whether or not to continue with their projects, the analysis of the biomass combustion case specifically focuses on the identification of these interactions.

In contrast to Chapters 2 to 5, the following chapter was not written in article-format. Since the theoretical starting points and the conceptual model were identical to the previous chapter, Chapter 6 contains only a short introduction and methodological section and no theoretical section. The case description, on the contrary, is more elaborated than in the previous chapters.

6 The case of biomass combustion

6.1 Introduction

This chapter focuses on perceived uncertainties related to the development and implementation of stand-alone biomass combustion plants for combined generation of heat and power (CHP).[1] Biomass combustion is considered to be an appealing solution in terms of the overall goal of achieving a more sustainable energy supply system, as it is a relatively simple technology to convert biomass into electricity and heat. In the combustion process, biomass (usually wood residues, waste wood or manure) is combusted to produce steam. The steam can be used for heating purposes and for the production of electricity (via a steam turbine). Although the electrical efficiencies of biomass combustion are lower compared to other thermo-chemical conversion technologies (like gasification or pyrolysis), the main advantage of biomass combustion is that the technology is in a more mature stage of development compared to the other technologies (Energie- en Milieuspectrum 1997; BTG 2005; IEA Bioenergy 2006).

Table 6-1 gives an overview of the development of biomass combustion plants in three countries which are leading with respect to the development and implementation of biomass combustion technology.[2] The growth in terms of number of plants and installed (electric and thermal) capacity illustrates that the diffusion of this technology has been increasing steadily over the past years. Based on the indicators defined in Chapter 1 (see Table 1-1) to make a distinction between the subsequent phases of technological development, this strong diffusion seems to indicate that biomass combustion technology has entered the acceleration phase.

In the Netherlands, the development and implementation of biomass combustion plants started some years later in comparison to the 'leading' countries (Scandinavian countries, Austria and Germany). As depicted in Figure 6-1, the first 2 Dutch plants reached the exploitation stage in 1997. Over the years, the number of plants has increased up to 6 operational plants in 2006 and at least 3 more plants are expected to be operational in the near future (see Figure 6-1) (Junginger and Faaij 2005; Tijmensen and De Vos 2005; Daey Ouwens 2005b). As the number

Table 6-1 Biomass combustion CHP plants installed in Austria, Finland and Denmark (based on Obernberger and Thek 2004).

Year	Austria			Finland			Denmark		
	No. of plants	E (MW_e)	Th (MW_{th})	No. of plants	E (MW_e)	Th (MW_{th})	No. of plants	E (MW_e)	Th (MW_{th})
1990	22	212	n.i.	n.i.	n.i.	n.i.	6	31	49
1995	25	223	n.i.	50	n.i.	n.i.	9	79	179
2000	32	234	n.i.	70	n.i.	n.i.	14	120	242
2003*	62	310	n.i.	80	2.000	5.000	16	209	416

No. of plants = Number of plants, E = electric capacity, Th = thermal capacity
* All data for 2003 were based on an outlook; n.i. = no indication

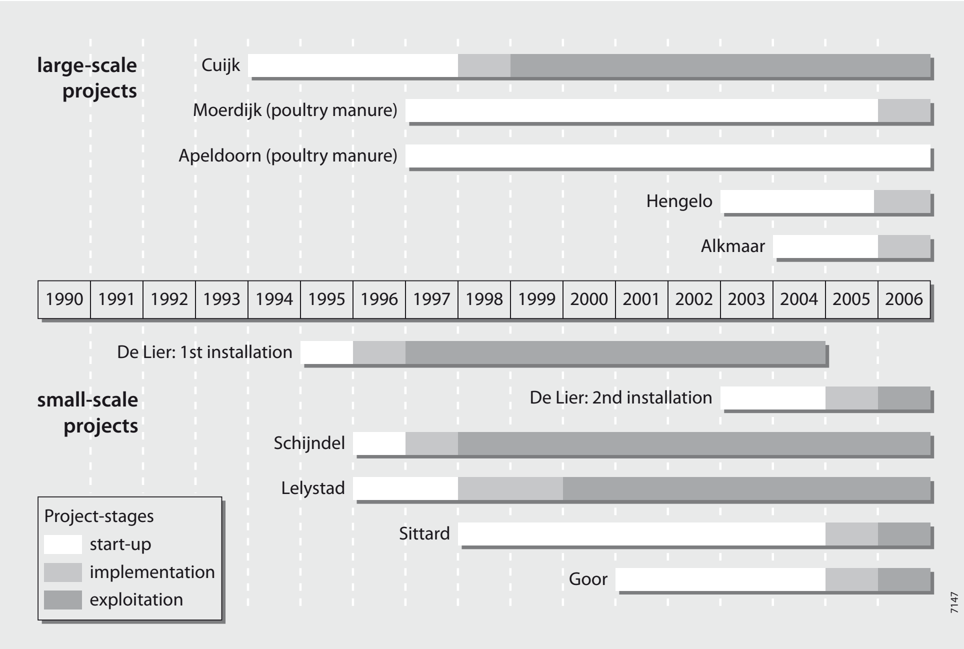

Figure 6-1 Timeline of stand-alone biomass combustion projects in the Netherlands.[3]

of operational plants increases over time, the technology gradually develops into a mature and ‘proven’ technology.

Building on the insights of the previous chapter, this chapter aims to deepen our understanding of how perceived uncertainties influence entrepreneurial action by analyzing what role perceived uncertainties have played in the development and implementation of biomass combustion installations in the Netherlands. Since interaction patterns between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action appeared to play a crucial role, it is important to understand how such interaction patterns emerge. Therefore, this chapter specifically focuses on the identification of different types of interaction patterns. The following research questions are posed:

1. *What are the dominant sources of uncertainty as perceived by the various entrepreneurs involved in development and implementation projects of biomass combustion in the Netherlands?*
2. *How do perceived uncertainties influence entrepreneurial action in different project stages?*
3. *What types of interaction patterns can be identified between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action?*

6.2 Notes on methodology

The same conceptual framework as described in Chapter 5 (see Section 5.2) was applied to this case study. The case study was performed in the autumn of 2006. The set of projects included in the case study consists of 10 stand-alone biomass combustion projects that started in different years over the last decade (see Figure 6-1). In contrast to the biomass gasification case, none of the Dutch biomass combustion projects was terminated after several years. Although there were some terminated projects, these projects were all discontinued soon after the start (i.e. directly after the performance of a feasibility study) (Green Balance 2004). Since the terminated projects were of such a short duration, the interviewees involved in these projects had difficulty recalling the projects and their perceptions of uncertainty regarding these projects. Therefore, these projects were excluded from the analysis. The remaining set of projects consisted of an equal number of large-scale projects of 15-30 MW_e (e.g. Cuijk, Hengelo, Alkmaar, Moerdijk, Apeldoorn) and small-scale projects of about 2 MW_e (e.g. De Lier, Schijndel, Lelystad, Sittard, Goor). Whereas the fuel used in most of these projects is wood (forest thinning, wood residues or waste wood), the projects in Moerdijk and Apeldoorn aim to use poultry manure.

Data for this case study was collected by conducting 12 interviews with the entrepreneurs who initiated the biomass combustion projects.[4] The same protocol for conducting and analyzing the interviews was used as in the biomass gasification case (see Section 5.3). In addition to the interviews, various types of documents (policy documents, scientific articles, project reports, professional journals and newspaper articles) were studied in order to triangulate the interview data.

6.3 The dominant uncertainties

Table 6-2 gives a general overview of the uncertainties that the interviewees perceived as important for their decisions concerning the development and implementation of biomass combustion. As Table 6-2 shows, political uncertainty and resource uncertainty were mentioned far more often (> 50%) than the other uncertainty sources and therefore can be considered most important for the innovation decisions of the entrepreneurs involved.

The reasons why the interviewees perceived political uncertainty as an important uncertainty source were first of all related to uncertainty about changes in the financial instruments (REB and MEP), which occurred frequently over the past years. In 2003, the fiscal support for renewable electricity (i.e. renewable electricity was exempted from the national energy tax, REB[5]) was replaced by the non-fiscal MEP-levy[6] that subsidizes the production of renewable electricity in the Netherlands (Kwant and Knoef 2004). In the period between 2003 and 2006, several adjustments were made to the MEP-instrument. In August 2006, just before the interviews took place, the government suddenly decided to put an abrupt stop to the MEP-instrument. This explains why uncertainty about the financial instruments was perceived to be important by all of the respondents (see Table 6-2). Other reasons for the importance of political uncertainty were related to uncertainty about the duration and outcome of the licensing procedure. In order to build a biomass combustion plant, a license needs to be obtained in which specific rules (including emission norms) are laid down. In the Netherlands, the licensing procedure of bio-energy projects is very complex and ambiguous, takes very long and offers many opportunities for neighbouring people and environmentalists to object to the license (Van Ree, Gerlagh et al. 2000; Lindeman 2004; Gerlagh and Lammers 2006). Since delay of the licensing procedure or imposition of strict emission rules can have serious consequences for the profitability of a project, the interviewees perceived great uncertainty about this issue.

The reason why resource uncertainty was perceived to be so important was first of all related to uncertainty about the availability, price and quality of biomass, since the market for biomass is

Table 6-2 General overview of the uncertainties that are perceived as dominant.[7]

Uncertainty source	Examples mentiond by interviewees (n=11)	Number of interviewees	% of interviewees
Technological	uncertainty about the technology itself	4	36
	uncertainty about the choice between different technological alternatives	0	0
	number of other examples mentioned by only 1 interviewee	0	0
	Total number of examples for technological uncertainty	**4**	
Political	uncertainty about the licensing procedure and emission regulation	6	55
	uncertainty about the financial instruments (REB, MEP)	11	100
	number of other examples mentioned by only 1 interviewee	1	9
	Total number of examples for political uncertainty	**18**	
Resource	uncertainty about biomass resources	9	82
	uncertainty about financial resources	3	27
	number of other examples mentioned by only 1 interviewee	2	18
	Total number of examples for resource uncertainty	**14**	
Supplier	uncertainty about the reliability of technology-suppliers	2	18
	uncertainty about the reliability of biomass-suppliers	0	0
	number of other examples mentioned by only 1 interviewee	0	0
	Total number of examples for supplier uncertainty	**2**	
Competitive	number of examples mentioned by only 1 interviewee	0	0
	Total number of examples for competitive uncertainty	**0**	
Consumer	uncertainty about selling the produced electricity and/or heat	4	36
	number of other examples mentioned by only 1 interviewee	0	0
	Total number of examples for consumer uncertainty	**4**	

relatively new and still unstable. A second reason for the importance of resource uncertainty was that the interviewees perceived uncertainty about the mobilization of financial resources both within the firm and external to the firm (from banks and other investors).

Another conclusion that can be drawn from Table 6-2 is that a majority of the interviewees did not perceive technological uncertainty as an important source of uncertainty with respect to biomass combustion projects. The interviewees explained that they consider biomass combustion to be a 'proven technology'. This perception was largely influenced by the successful development and implementation of biomass combustion plants abroad (especially in Scandinavian countries, Austria, Germany and England[8]).

6.4 Dynamic project analysis

This section consists of a dynamic analysis of the projects depicted in Figure 6-1. The aim of the project analysis was to analyze how the entrepreneurs' perceptions of uncertainties, their motivation and their decision whether or not to act evolve over time. The section starts with the projects that have reached the exploitation stage, then discusses the projects that are currently in the implementation stage and ends with the project that is still in the start-up stage. The project descriptions all start with a chronological overview and end with an analytical paragraph.

6.4.1 The exploitation stage

The projects are described in the order in which the biomass combustion installations became operational (see Figure 6-1).

De Lier

In 1984, a horticulturist in De Lier started experimenting with biomass combustion in order to heat his greenhouses. Since the wood combustion plant was not operating successfully, the horticulturist decided to stop his activities. Mr De Lange, manager of timber company De Lange BV which delivered the wood residues for the project, decided to take-over the plant in order to continue wood combustion activities. For Mr De Lange, combustion of wood was an opportunity in order to exploit a stream of residue products which would otherwise be expensive to dispose. (Gelderblom 2006)

Since the experiments of the horticulturist had not delivered a well-functioning plant, Mr De Lange decided to build a new wood combustion installation. In 1995, Mr De Lange hired a consultancy firm (Agro Adviesburo) and an engineering company (TNO) to assist in the start-up of the project and to carry out a feasibility study. An installation for combined generation of heat and power (CHP) with a thermal capacity of 3 MW_{th} (sufficient to provide heat to three greenhouses) turned out to be the best option (SenterNovem 2004). In the following years, a license was obtained, a technology developer (Vepro) was contracted to deliver the installation and contracts were signed for the supply of heat to three nearby horticulturists and for the supply of electricity to the local energy distribution company. Mr De Lange was very enthusiastic about wood combustion and perceived little uncertainties (Gelderblom 2006). In 1997, the installation was operational. However, several technological problems arose and the entrepreneur's perception of technological uncertainty increased. The oven melted before the necessary temperature was reached, leading to poor combustion of the biomass and by this to insufficient production of electricity and excessive emissions (SenterNovem 2004; Gelderblom 2006). The increase of perceived technological uncertainty was accompanied by an increase of perceived uncertainty about the reliability of the technology supplier. Although technology developer Vepro was experienced in the development and implementation of wood combustion installations for timber companies, Vepro had never before built a CHP installation which produced both high-pressure steam (needed for heating of the greenhouses) and electricity. To make things even worse, Vepro went bankrupt within a year, and thereby leaving De Lange with a poor-functioning installation and no expertise. Thus, the exit of the technology supplier also confronted the entrepreneur with uncertainty about the knowledge needed to continue the project (i.e. a form of resource uncertainty). Mr De Lange realized that the successful development and implementation of a biomass combustion plant was far more complicated than he had expected. He recognized that his implicit faith in the technology developer had been misplaced and that uncertainties had been heavily underestimated. As a result of the technical problems, the project was delayed and no electricity could be delivered until the end of April 1999. (SenterNovem 2004; Gelderblom 2006) In order to find a solution for the technical problems, several other technology developers were consulted. Despite the attempts to improve the installation, the technical problems remained. The electricity output never reached the designed capacity (only 200 kW_e was produced instead of

$750kW_e$, SenterNovem 2004) and, because of the excessive emissions, the installation was unable to comply with the emission rules (Gelderblom 2006).

The local authorities responsible for the environmental regulation had tolerated the situation for many years, but since all the attempts to solve the technological problems had failed they finally decided to put an end to the situation. In 2003, the local authorities compelled Mr De Lange to choose between stopping his wood combustion activities and building a new installation. Although Mr De Lange had encountered great technological setbacks in his own project, he had noticed that other wood combustion installations were functioning well. As a result of the success of these other installations, Mr De Lange was still attracted by the opportunities that the combustion of wood residues had to offer. Despite the technological setbacks in his own project, Mr De Lange therefore decided to continue his activities and reinvested in the project to be able to build a new installation. Thus, successful external developments formed such a strong motivation that they seemed to counteract the negative results from the entrepreneur's own experience. (Gelderblom 2006; De Lange 2007)

The financial feasibility of the reinvestment plans was largely dependent on the financial support of the government. At the time, the Dutch government had just introduced a new financial instrument to stimulate the production of renewable energy: the MEP. For an entrepreneur like Mr De Lange, manager of a small company with hardly any experience with these types of governmental instruments, uncertainty about the application procedure and the outcome of the procedure (whether or not a MEP-subsidy would be obtained) was perceived very high since errors or omissions in the application form could lead to a rejection by the responsible authorities (Gelderblom 2006). Fortunately, Mr De Lange managed to obtain a MEP-subsidy and thereby to reduce political uncertainty. Other important sources of perceived uncertainty, were uncertainty about the technology itself and about the reliability of the technology developer. Having learned from prior experiences, Mr De Lange aimed to minimize these uncertainties by clearly specifying the technical requirements of the new installation so that the combustion process would be optimally attuned to the project-specific conditions (such as the specific characteristics of the feedstock). Furthermore, Mr De Lange was more careful in selecting a technology developer and based his choice on conversations with several technology developers and visits to other wood combustion CHP installations. Technology developer Vyncke was hired for the construction of the new furnace and boiler, because of Vyncke's experience with this type of small-scale wood combustion installation.[9] However, in order to save money, Mr De Lange decided to reuse the steam-turbine of the old installation which was constructed by Nadrowski. In January 2006, the new installation was operational. Again, the installation did not reach the designed electricity production capacity. Vyncke and Nadrowski accused each other of causing the problems. Investigation by external experts indicated that the origin of these problems was found to be in the turbine. At the moment of the interviews (end of 2006), the technology developers were still making adjustments to the installation in order to improve the performance of the turbine and to optimize the combustion conditions for the specific feedstock characteristics (i.e. 'learning-by-doing' in order to reduce perceived technological uncertainty). The installation was still not functioning optimally, but progress was being made. (Gelderblom 2006; De Lange 2007)

Thus, in the start-up stage and the implementation stage of this project, the entrepreneur perceived little uncertainties and did not undertake any activities in order to manage these uncertainties. The entrepreneur was very motivated to engage in biomass combustion activities because of enthusiasm about the opportunities that the new technology had to offer. In the exploitation stage, technological problems and changes in the actor constitution (bankruptcy and withdrawal of the technology developer) occurred. These factors led to an accumulation of various perceived uncertainties: technological uncertainty, supplier uncertainty and uncertainty about the availability of knowledge which was needed for the project (a form of resource uncertainty). The activities which the entrepreneur initiated to reduce these uncertainties (knowledge acquisition and experimenting with the technology) were unsuccessful. Despite the increased level of perceived uncertainty in this stage of the project, the entrepreneur decided to continue biomass combustion activities by building a new installation. The continuation of entrepreneurial action can be explained by the high motivation of the entrepreneur. The motivation of the entrepreneur had been high from the start of the project and was positively reinforced by the success of external technological developments with respect to biomass combustion technology.

Schijndel

Timber Company HIS (Houtindustrie Schijndel) owned an installation for the combustion of wood residues. The heat that was produced in the combustion process was used within the company. In the summers, when the company's heat demand was low, the installation's capacity was only partially used; leaving HIS with a surplus of waste wood. When, in addition, the Dutch government announced to stiffen the emission guidelines for air (NER[10]), exploitation of the installation became economically unfeasible since an expensive gas cleaning filter had to be installed in order to satisfy the new emission rules. In 1996, Mr Van Roy – manager of HIS – decided to search for alternative options to use the company's wood surplus. Visits to several wood combustion projects in Germany made Mr Van Roy attracted to the idea of building a new wood combustion installation for combined generation of heat and power (CHP). The electricity generated by this installation could be sold to the local energy company and heat would be produced only as a by-product. However, this plan turned out to be economically unfeasible. Since Mr Van Roy had become very enthusiastic about this type of wood combustion installation, he decided to proceed with the plans anyhow. A study was carried out in order to calculate the minimum electricity production capacity which would be needed to make the installation economically feasible. This turned out to be 1,1 MW_e. In order to reach this capacity, additional waste wood would have to be obtained. This was not considered as a problem, since at that time waste wood still had a negative market value (meaning that HIS received money for the waste wood disposal). (Tijmensen and De Vos 2005; Van Roy 2006)

Since banks were unwilling to invest in such an innovative project (the biomass combustion installation was one of the first in the Netherlands), Mr Van Roy perceived uncertainty about the mobilization of financial resources. Luckily, an unexpected financial opportunity arose. Since one of the projects which had been granted an investment subsidy by the Dutch government was cancelled, the government had spare money (about 400.000 Euros) to invest in a sustainable energy project. Mr Van Roy did not want to miss out on the opportunity of receiving this investment subsidy and therefore decided to go ahead with the project hastily. The subsidy-proposal was granted and implementation of the plant started soon afterwards (in November 1996). (Van Roy 2006)

Four months later (in March 1997), construction was finished. When commissioning activities started, several technical problems arose. The installation did not reach the designed electricity production capacity and malfunctioning of the cooler led to damage of the installation (Van Roy 2006). Mr Van Roy became to realize that he had heavily underestimated uncertainties. Although the technical components were all 'proven', the components had never before been integrated in this specific constellation. Furthermore, technology developer Vyncke (which had been contracted to deliver the main parts of the installation and to coordinate the construction activities) was specialized in combustion installations, but had never before constructed a CHP installation for the combustion of biomass (Tijmensen and De Vos 2005). As a result, Mr Van Roy perceived increasing uncertainty about the technology itself and about the knowledge needed to successfully develop and implement a biomass combustion installation (a form of resource uncertainty). The project was delayed as far more time was needed to successfully implement this new technology than Mr Van Roy had expected. In addition, cooperation problems between technology developer Vyncke and several sub-contractors further delayed the project (Tijmensen and De Vos 2005; Van Roy 2006). As a result, the costs of the project were running high and Mr Van Roy perceived growing uncertainty about the mobilization of additional financial resources. To make things worse, uncertainty about the price and availability of biomass resources also increased over time due to the rapidly expanding demand for waste wood. Since Mr Van Roy had invested a substantial amount of money from HIS in the project, the project almost had fatal consequences for the survival of the timber company (Tijmensen and De Vos 2005; Van Roy 2006).

By this time, Mr Van Roy recognized that it would have been wiser if he had been more cautious instead of rushing matters out of enthusiasm. In retrospect, Mr Van Roy acknowledged that his initial enthusiasm had made him ignore uncertainties. If he would have been more aware of all the problems and uncertainties that he was to encounter further on in the project, he would never have started the project. On the other hand, though, he believed that a lot of the problems could have been prevented if more time and money had been invested in the start-up stage for developing a thorough business plan and contracting experts to coordinate the project in order to reduce uncertainties. (Tijmensen and De Vos 2005; Van Roy 2006) However, things could not be made undone. The only choice left was to persist or to withdraw. Despite the accumulation of uncertainties, Mr Van Roy remained motivated and decided to continue investing in the project. His motivation seemed to be based on a feeling of 'entrapment': since already a lot of time and money was invested in the project, he believed that there was no other option than to continue in order to regain these investments. Stopping now would be a waste of time and money. Fortunately, his efforts started to pay off. After two troublesome years in which several adjustments were made to the installation, the technical problems were finally solved (Tijmensen and De Vos 2005; Van Roy 2006). Thus, experimenting with the installation ('learning-by-doing') helped to reduce technological uncertainty. Furthermore, in 2003, the Dutch government introduced a new financial instrument (the MEP-subsidy) which stimulated the production of renewable electricity. Thanks to the MEP-subsidy, the exploitation of the installation finally became profitable after many years of loss-making. (Van Roy 2006)

However, the MEP-subsidy for this installation ended in March 2007 and the installation was approaching the end of its technical lifespan. After having overcome all the hurdles, Mr Van Roy did not want to stop his biomass combustion activities when things finally made a turn for the better. Mr Van Roy felt that the expertise built up over the years would be wasted if the project stopped. Moreover, Mr Van Roy noticed that sector-wide technological-development activities had resulted in considerable technological improvements. The favourable MEP-policy and the success of these external technology development activities enforced Mr Van Roy's motivation to reinvest in the project. At the moment of the interview, Mr Van Roy was working on concrete plans to rebuild the old installation so that biomass combustion activities could continue for another 10 years. However, uncertainty about the MEP-subsidy may still prevent Mr Van Roy from executing his renovation plan. Although the government granted Mr Van Roy's request for a MEP-subsidy, this judgment was still not final. (Van Roy 2006)

Thus, the project in Schijndel shows remarkable similarities to the project in De Lier. These biomass combustion plants were the first two operational plants in the Netherlands (see Figure 6-1). Just like in the project in De Lier, the entrepreneur of this project initially perceived little uncertainties and was extremely motivated to engage in biomass combustion activities because of enthusiasm about the opportunities that biomass combustion technology had to offer. The only source of uncertainty that the entrepreneur experienced during the start-up stage, was uncertainty about the mobilization of financial resources. This uncertainty was quickly reduced under the positive influence of external events (resulting in the availability of an investment subsidy). However, when construction of the plant was finished, technological problems arose. These technological problems led to an increase of technological uncertainty and uncertainty about the availability of knowledge. The experimenting activities initiated to reduce these perceived uncertainties were unsuccessful. The uncertainties remained and the project was delayed. This delay, in turn, resulted in uncertainty about financial resources and biomass resources. Thus, new sources of uncertainty emerged on top of the already-existing uncertainties. In this way, a negative interaction pattern was built up. However, the entrepreneur decided to continue biomass combustion activities despite the increased level of perceived uncertainty. Just like in the project in De Lier, the decision to continue entrepreneurial action was the result of the extremely high motivation of the entrepreneur. Even when the biomass combustion activities became a threat to the company's survival, the entrepreneur remained motivated to continue investing in the project (i.e. 'entrapment'). During the exploitation stage, the entrepreneur's motivation became more rational-based. Favourable institutional and technological changes external to the project (the introduction of the MEP subsidy and the successful external technology development activities) positively influenced the motivation of the entrepreneur to invest in the rebuilding of the installation. Thus, the project description showed that motivation can change from 'blind' enthusiasm at the beginning, to 'entrapment' during the implementation stage and finally, when both the know-how of the entrepreneur and the technology have further-developed, to a more rational-based motivation to engage in the development and implementation of an emerging technology.

Cuijk

The first large-scale (25 MW_e) stand-alone biomass combustion plant that has been built in the Netherlands is located in Cuijk. The initial ideas to build a stand-alone biomass combustion plant originated from 1994. Driven by governmental policies to reduce CO_2-emissions, energy company PNEM (later succeeded by Essent[11]) became interested in producing electricity out of biomass. An engineering firm was hired to perform a feasibility study in which several biomass conversion technologies were compared. One of the main criteria of the feasibility study was that the technology had to be 'proven'. The technological uncertainties of biomass gasification technology were perceived to be too high. In order to keep technological uncertainties to a minimum, biomass combustion was considered to be the best option. (Energie- en Milieuspectrum 1997; Duurzame Energie 1997b; Remmers 2006)

Before making the final investment decision, an analysis was made to identify the main uncertainties involved in developing and implementing a large-scale biomass combustion plant. As a result of the extensive feasibility study, technological uncertainty was perceived to be low. In order to keep uncertainty about the reliability of technology developers to a minimum, an elaborate selection procedure was carried-out. Technology developer Siemens was chosen as the main contractor, responsible for the coordination of the project and the cooperation between the sub-contractors (Kvaerner and Heijmans). The feasibility study furthermore showed that the availability of biomass resources did not form a threat. By cooperating with the largest national biomass supplier, Staatsbosbeheer, uncertainty about the supply of biomass was reduced as much as possible. (Remmers 2006)

The reason for locating the combustion plant in Cuijk, was that the plant would deliver heat to a nearby paper-mill and a new residential area. However, the construction of a heat infrastructure was expensive and the financial instruments of the government only supported the production of electricity and not the production of heat. Due to these financial reasons, the supply of heat was not a very appealing option for PNEM. However, environmental organizations and the governmental authorities responsible for the subsidy and licensing procedure of the plant opposed to the idea of simply discarding the heat. For PNEM, this issue led to great uncertainty if the project would be able to receive a subsidy and license (i.e. political uncertainty). PNEM organized several communication events to discuss this issue with environmental organizations, neighbouring people and governmental authorities and thereby to gain support for the project. This strategy was effective, as PNEM managed to cancel the delivery of heat without endangering the subsidy application or licensing procedure. Thus, political uncertainty was reduced. (Remmers 2006)

Having reduced the different sources of perceived uncertainty as much as possible, the top managers of PNEM decided to go ahead with the plan and, in 1997, the final investment decision was made. Construction of the plant started in 1998 and finished a year afterwards, according to schedule. At the beginning of the exploitation stage, several technical problems occurred (i.e. 'bed agglomeration' and wear-out of the installation). The origin of these problems was found to be in the quality of the biomass, which contained too much sand. By being more selective in which biomass streams to use and by adding a sieve to remove the sand from the fuel, these problems were quickly solved. Another problem was that the designed capacity of 25 MW_e was not reached, because the moisture content of the biomass was about 10% higher than expected. After some adjustments to the furnace, this problem was solved as well. (Tijmensen and De Vos 2005; Remmers 2006) Since the technological problems were solved quickly and were regarded as normal 'teething problems', perceived technological uncertainty remained low.

Since then, the installation has been operating well and no other problems have occurred. The strategy of the entrepreneur to identify uncertainties and reduce them as much as possible has paid-off. However, the entrepreneur claims that the continuation of this project is being threatened by perceived uncertainty about future governmental policy and the developments of the biomass-market. Essent is unwilling to continue with the exploitation of this plant if the cost price for biomass exceeds the selling price for renewable electricity. Since the demand for biomass has been increasing rapidly over the past years, Essent perceives growing uncertainty about the availability and price of biomass. Adding to this, Essent perceives uncertainty about future governmental policy because the selling price for renewable electricity is largely influenced by financial support from the government. The 10-year subsidy that this project has been receiving for the production of renewable electricity (MEP) will end in 2009. Furthermore, the Dutch government has recently cancelled the MEP-instrument and has not yet introduced a new financial instrument to support the production of renewable energy. Therefore, Essent declares to be very uncertain if the Cuijk-project will receive governmental support in the future. (Remmers 2006)

Thus, the entrepreneur of this project was more aware of the various uncertainty sources than the entrepreneurs of the previous projects (De Lier and Schijndel). Already in the start-up stage, the entrepreneur initiated various activities (e.g. perform studies of the various technological alternatives, the biomass market and the technology suppliers; enter into a cooperation agreement with biomass-suppliers; lobby among opponents in order to gain support) in order to reduce perceived uncertainties as much as possible. As a result of these successful activities, perceived uncertainties decreased and, consequently, the motivation of the entrepreneur to continue his activities was reinforced. Thus, a positive interaction pattern was created. When the plant was first put into use, technological problems arose. Interesting to conclude from the project description, is that these technological problems did not lead to an increase of perceived technological uncertainty. The reason for this is that the experimenting activities (adjusting of the furnace) that were initiated to solve the problems quickly led to success. Another interesting finding is that the motivation of this entrepreneur differs from the entrepreneurs of the previous projects (De Lier and Schijndel). In the Cuijk-project, the motivation to implement a biomass combustion plant had nothing to do with enthusiasm for the new technology, but was based on more rational grounds (i.e. selecting a bio-energy technology with minimal technological uncertainties). Furthermore, the motivation of this entrepreneur is more profit-oriented. In contrast to the entrepreneur of the Schijndel-project, the entrepreneur of this project is unwilling to continue with the project if uncertainties (about future financial support from the government and about the price for biomass) become too much of a threat to the profitability of biomass combustion.

Lelystad

In 1996, energy company Nuon together with the local municipality of Lelystad searched for ways to make the existing district heating system more sustainable. The idea arose to build a small-scale biomass installation in order to produce heat out of locally-available biomass. After examining several biomass conversion technologies (gasification, digestion and combustion), Nuon decided to opt for a biomass combustion plant for combined generation of heat and electricity (CHP). Because of several successful biomass combustion projects of technology developers in Austria, Scandinavia and Germany, the technological uncertainties of biomass combustion were perceived to be small. Since Nuon had no experience with biomass combustion projects, the development and implementation of the plant were outsourced to an international consortium which consisted of technology developers Polytechnik from Austria and Holec from the Netherlands. Because of the elaborate selection procedure on which this decision was based, uncertainty about the reliability of these technology developers was perceived to be low. (Tijmensen and De Vos 2005; Schiricke 2006)

The main sources of uncertainty that Nuon perceived in this stage of the project, were uncertainty about the availability, quality and price of biomass and about the reliability of biomass-suppliers. Since the project in Lelystad aimed at using locally-available biomass (i.e.

wood residues from local forests and parks), the supply of biomass was limited. In addition, Nuon perceived uncertainty about the reliability of biomass-suppliers since the trade in biomass was still relatively new. By closing a long-term contract with Staatsbosbeheer, the largest national biomass-supplier, these uncertainties were reduced.[12] (Schiricke 2006)

In 1998, Nuon had obtained all the necessary licenses and construction of the plant started. However, during the construction of the plant, the consortium of technology developers went bankrupt and could not live up to the agreements (Tijmensen and De Vos 2005; Schiricke 2006). This event had large impact on the project as Nuon seriously doubted whether to terminate the project. Because Nuon had relied heavily on the expertise of the technology developers, perceived uncertainty about the reliability of technology suppliers and about how to acquire the knowledge which was needed to continue the project (i.e. a form of resource uncertainty) greatly increased. After many discussions, Nuon decided to continue by taking-over the coordination of the project itself and contracting three Dutch engineering companies to provide the technological know-how. By now, though, the project was seriously delayed and the budget was exceeded. Although Nuon could easily finance the project, the project team perceived uncertainty about the mobilization of financial resources needed to continue the project. Because of the unforeseen costs, the project no longer satisfied the investment criteria on which the original investment decision was based. In addition, due to the liberalisation of the energy market (which was initiated in 1998), Nuon's investment criteria had become more severe and the company's focus had shifted towards scaling-up instead of investing in local, small-scale projects like the Lelystad-project. As the withdrawal of the initial technology developers had led to an accumulation of perceived uncertainties, the decision whether or not to reinvest became a constant issue of debate throughout the implementation stage. (Schiricke 2006)

In January 2000, construction of the plant was finally finished. In order to regain the high investment costs and thereby reduce uncertainty about the mobilization of financial resources, Nuon decided to save costs by experimenting with the use of cheaper, low-quality wood. However, the low-quality of the biomass was causing technological problems (i.e. poor combustion conditions, conglomeration and wear-out of the installation). Because the installation was believed to be suited for a large diversity of biomass streams, these problems were underestimated and technological uncertainty increased. Thus, uncertainty about financial resources negatively influenced the perception of technological uncertainty. Fortunately, Nuon persisted. By experimenting with the installation, Nuon learned how to optimize the technical and economic performance of the installation for different biomass streams and thereby to reduce technological uncertainties. Furthermore, by building-up expertise, Nuon was able to become independent of the knowledge of technology developers. (Schiricke 2006) Since 2002, the installation has been functioning well.

Although most uncertainties have been reduced, some uncertainties have remained. Just like energy company Essent with respect to the Cuijk-project, Nuon declares that perceived uncertainties about the financial policy of the Dutch government and about the developments of the biomass-market are threatening the continuation of the Lelystad-project. Since the demand for biomass has increased over the years and the long-term contract with biomass-supplier Staatsbosbeheer will end in 2010, Nuon perceives great uncertainty about the future availability and price of biomass. Furthermore, the 10-year subsidy that the Lelystad-project has been receiving for the production of renewable electricity (MEP) will end in 2009. According to Nuon, biomass combustion projects can only be economically feasible with financial support from the government. Therefore, perceived uncertainty about the future financial policy not only hinders Nuon in the continuation of the Lelystad-project, but also in initiating new biomass combustion projects. (Schiricke 2006)

Thus, similar to the Cuijk-project, the entrepreneur of this project was well aware of various uncertainty sources and initiated several activities (perform technological and market studies, enter into cooperation agreements with biomass suppliers and technology suppliers) to minimize perceived uncertainties in the start-up stage of the project. However, not all of these activities turned out to be successful on the longer-term. Despite the elaborate selection procedure which was aimed at reducing uncertainty about the reliability of the technology suppliers, the technology suppliers failed to live up to the agreements and withdrew from the project during the implementation stage. This change in actor constitution (a project-internal factor) triggered the emergence of a negative interaction pattern, since one source of uncertainty directly or indirectly influenced the increase of another source of uncertainty. Namely, the change in actor constitution resulted in an increase of supplier uncertainty and uncertainty about the knowledge required for the project. The activities that were needed to reduce these uncertainties (i.e. knowledge acquisition) led to delay. The delay both directly (via cost overrun) and indirectly (via institutional change: i.e. stricter financial criteria as a result of the liberalisation of the energy market) resulted in an increase of uncertainty about the mobilization of financial resources. To make things worse, the experimenting activities which aimed at reducing uncertainty about financial resources resulted in an increase of technological uncertainty. Luckily, the experimenting activities eventually became successful in reducing the perceived uncertainties and thereby the negative interaction pattern was put to a stop. The reduction of perceived uncertainties seems to have come just in time. As a result of external factors (liberalization of the energy market), the motivation to invest in the project had diminished. Similar to the Cuijk-project, the entrepreneur of this project is no longer willing to continue with biomass combustion activities if uncertainties (about future financial support from the government and about the price for biomass) become too much of a threat to the profitability of biomass combustion.

Sittard

In 1998, the municipality of Sittard contracted Mrs Aarts, manager of a gardening business (Hacalls), to make an overview of the local biomass streams and to examine how these streams could best be used. In the same period, energy company Essent was constructing a district heating system in order to deliver heat to a new residential area. The heat would be produced with a CHP installation fuelled by natural gas. However, since Essent had not yet implemented the CHP installation, Mrs Aarts put forward a proposal for building a biomass-fuelled CHP installation instead. The municipality of Sittard was very enthusiastic about this idea, but Essent was more reluctant. Mrs Aarts drew up an elaborate business plan in order to demonstrate the feasibility of her plans. In 2003, after several conversations with Essent, Mrs Aarts proposed to develop and implement the biomass CHP installation herself. She established a new corporation, called BES (Biomass Energy plant Sittard). But before deciding to go ahead with the project, Mrs Aarts wanted to eliminate uncertainty about the market for heat. Since the subsidy policy of the Dutch government only aimed at the renewable production of electricity and not of heat, uncertainty about the market for heat formed a serious threat for the feasibility of biomass projects which primarily focus on heat-production (like the one in Sittard). By signing long-term contracts with

Essent and Vixia (the owner of a local industrial site) for the supply of heat, Mrs Aarts was able to reduce this uncertainty. (Aarts 2006)

The next step was to arrange the finances of the project. Since Mrs Aarts could not finance the project alone, she perceived great uncertainty about the mobilization of financial resources. To make things complicated, uncertainty about financial resources was linked up to uncertainty about biomass resources. Based on her experience in the gardening business and her extensive study of locally-available biomass streams, Mrs Aarts herself did not perceive uncertainty about the long-term availability and price of biomass resources. The installation would use low-quality biomass (i.e. integral green waste[13]) which was relatively cheap and locally available. However, in the perception of the banks, uncertainty about the long-term supply of biomass could endanger the success of the project. The banks were unwilling to issue a loan without guarantees about the long-term supply of biomass. By closing long-term contracts with the municipality of Sittard and other local municipalities, Mrs Aarts managed to comply with the demand of the banks and thereby to eliminate resource uncertainty. (Aarts 2006; SenterNovem 2006)

The original business plan of Mrs Aarts was based on biomass gasification technology. Theoretically, biomass gasification technology could achieve a higher efficiency than combustion. However, the disadvantage of gasification was that the technology was not yet a reliable and proven technology. Therefore, Mrs Aarts perceived uncertainty if biomass gasification was indeed the best technological option. In reaction to this uncertainty, Mrs Aarts kept searching for different technological alternatives. When Mrs Aarts came into contact with Aldavia, an Austrian technology developer of biomass combustion installations, she decided to opt for biomass combustion instead. Namely, biomass combustion was in a more mature stage of development than gasification and the combustion installation of Aldavia satisfied the project-specific requirements of producing heat and electricity out of low-quality biomass. Thus, perceived technological uncertainty was also reduced. (Aarts 2006)

Despite the strategy of Mrs Aarts to identify uncertainties and reduce them as much as possible, the start-up stage of the project did not proceed without risks. Since the start of the project in 1998, both the financial instruments and the emission regulation had changed multiple times. More than once, Mrs Aarts had to adjust her business plan to respond to these policy changes. As a result, Mrs Aarts perceived great uncertainty about the reliability of the Dutch government. Political uncertainty became even stronger due to the long licensing procedure of the project. Whereas environmental organizations supported the project, a private individual objected to the license. Although his motives to object did not have much to do with the project itself, the objections led to a serious delay of the licensing procedure. (De Laat and Verhagen 2005; Aarts 2006) Uncertainty about the duration and outcome of the licensing procedure formed a serious threat to the project. If the installation was not operational on the 1st of January 2006, the heat-deliverance contract would no longer be valid. Despite the fact that Mrs Aarts was officially not allowed to start with the construction of the plant before she had obtained all the necessary licenses, she could not afford to wait. Deciding to put the project temporarily 'on hold' was no option as delay of the project would lead to the rise of another, and likely even bigger, uncertainty concerning the market for heat. Mrs Aarts felt that she had no other option than to take the risk. As a result, construction of the plant started while the licensing procedure was still not completed. Fortunately, the objections were rejected, the license was granted.

Construction of the plant finished in time. In January 2006, the production of heat started. During the first few months, the installation encountered several technical problems due to the relatively large pollution of sand, iron scrap and stones in the biomass. These problems were quickly solved by adding sieves and magnets to the fuel-inlet which remove the pollution before the biomass enters the oven. Therefore, perceived technological uncertainty remained low. The production of electricity started in August 2006, when the turbine was installed.

Unfortunately, in May 2007 (about half a year after the interview), a fire broke out which burned down almost the entire plant (AD 2007; Energieraad 2007). A technical investigation demonstrated that the fire was caused by a material defect in the heat exchanger (Dagblad de Limburger 2007; Vermaas 2007). Despite this major setback, the entrepreneur decided to continue with the project. At the moment of writing (October 2007), the installation is being rebuilt. The renovation is expected to be finished in May 2008 (Dagblad de Limburger 2007). Although this incident did not result in the termination of the Sittard-project, this incident can have a considerable, sector-wide impact on the perceptions of uncertainty from this moment onward.[14]

Thus, the Sittard-project shows that perceptions of uncertainties can differ largely between different types of actors. Whereas the entrepreneur was confident about the mobilization of biomass resources for low prices, banks perceived uncertainty about this aspect. This uncertainty was so strong, that it prevented the banks from investing in the project. As a result, the entrepreneur perceived uncertainty about the mobilization of financial resources. In this way, different types of perceived uncertainty negatively interact with each other. Another interesting finding is that interactions between different uncertainty sources can sometimes result in a trade-off situation. During the start-up stage, objections to the license created uncertainty about the outcome of the license application. Waiting until this uncertainty was resolved, would mean a serious delay of the implementation stage. The threat of a delay was causing an increase of consumer uncertainty (uncertainty about the market for heat). Thus, political uncertainty indirectly influenced consumer uncertainty. As it was impossible to reduce both uncertainties at the same time, the entrepreneur was facing a trade-off between political uncertainty and consumer uncertainty. The continuation of the project is to a large extent explained by the strong motivation of the entrepreneur. Although the entrepreneur was well aware of the various sources of uncertainty, the entrepreneur was willing to take risks in order for the project to proceed according to schedule. This strategy could have backfired, but luckily it didn't and uncertainties reduced. A final remark with respect to the Sittard-project, is that the project description confirms the observation regarding the Cuijk-project that technological problems not always result in an increase of perceived technological uncertainty.

Goor

In 2001, energy company Cogas and organic waste recycling company Bruins & Kwast decided to cooperate in the realization of a small-scale biomass plant in order to convert contaminated waste wood (so-called 'B-quality' wood) into renewable electricity and heat. Bruins & Kwast was to deliver the waste wood and use part of the produced heat, whereas Cogas would sell the renewable electricity to its customers. Together with an investment company (Participatiemaatschappij Oost Nederland) which financially supported the project, a joint venture was established: BioEnergieTwente. (Kwast 2006; Van Hutten 2006)

One of the starting points of the project was that the technology had to be 'proven'. The entrepreneurs contracted engineering firm Optimum and consulted several other technical experts in order to determine the feasibility of biomass combustion and biomass gasification. Based on this information, the choice was made for biomass combustion technology. Biomass combustion was believed to be a reliable and 'proven' technology, whereas the practical experience of biomass gasification was still too limited in order to qualify for commercial application.[15] As a result of this careful technological analysis, technological uncertainty was perceived to be small. (Kwast 2006; Van Hutten 2006)

The main source of uncertainty in this stage of the project was political uncertainty. The final investment decision was strongly dependent on financial support from the government. During that period, the Dutch government had announced the introduction of a new financial instrument to support the production of renewable electricity (the MEP). However, in 2002, the government decided to postpone the introduction of this instrument. As a result, the entrepreneurs perceived great uncertainty about the financial policy of the government and decided to put the project on-hold. When the new instrument finally came into force in 2003, the project was restarted and subsidy was obtained for a period of 10 years. However, due to this uncertainty the project had been delayed for a year. (EnergieNederland 2006; Kwast 2006)

Besides uncertainty about the financial policy of the government, the entrepreneurs also perceived uncertainty about the duration and outcome of the licensing procedure. The installation in Goor was the first biomass combustion plant in the Netherlands fuelled by contaminated waste wood (instead of 'clean' biomass such as wood thinning or residue products from the wood industry). The local authorities responsible for granting the license had no experience with the procedure for this kind of installation and, due to the ambiguous and partly overlapping emission regulation, perceived uncertainty which emission rules should be imposed in the license. In order to reduce uncertainty about the licensing procedure, the entrepreneurs provided detailed information about the installation. These activities helped to gain support for the project and to complete the licensing procedure without further problems. (Van Hutten 2006)

The final hurdle that had to be taken before making the final investment decision was to allocate financial resources to the project. The own funds that the three partners invested in the project was insufficient to cover all the costs. However, several attempts to obtain a loan failed. Since biomass combustion projects were still rather new, many banks perceived the uncertainties with respect to the project to be too high (Feil, Vos et al. 2005). This, in turn, created uncertainty for the entrepreneurs if they would be able to mobilize the financial resources needed for the project. Finally, the entrepreneurs managed to obtain a loan from two banks (Friesland Bank and Triodos Bank). However, many conversations had been needed to influence the banks' perceptions of uncertainty. (Feil, Vos et al. 2005; Van Hutten 2006)

As the activities that the entrepreneurs had undertaken to reduce uncertainties had been successful, the entrepreneurs decided to proceed to the implementation stage. Construction of the plant started in April 2005 under the management of engineering firm Optimum. The technological components were delivered by two technology developers from Germany and Austria. The installation is operational since August 2006. Although some technical problems occurred (the integration between the technological components had to be optimized for the specific characteristics of the fuel), perceived technological uncertainty did not increase. The technological problems did not alter the opinion of the entrepreneur that biomass combustion was a 'proven technology', since the entrepreneur realized that even the implementation of 'proven technology' usually involves teething problems. The entrepreneurs try to improve the performance of the installation by means of 'learning-by-doing' and have concrete plans to build a second biomass combustion plant (Havermans 2006; Van Hutten 2006).

Thus, the Goor-project shows that entrepreneurs can apply different strategies for dealing with perceived uncertainties. The above project-descriptions mostly gave examples of the strategy to reduce perceived uncertainties by initiating various activities (e.g. perform feasibility studies or close cooperation contracts). Apart from the strategy to manage uncertainties by taking action, the Goor-project also gives an example of a different strategy for dealing with perceived uncertainties: postpone action until the perceived uncertainties have been reduced (by others or by time). Namely, during the start-up stage, the entrepreneur decided to put the project on-hold until uncertainty about the introduction of a new policy instrument (the MEP) had been reduced. Comparison of the projects in Goor and Sittard shows that a precondition for using this 'postpone' strategy is that the consequences of delaying the project need to be limited. In the Sittard-project, reducing political uncertainty by delaying the project would result in an unacceptable increase of consumer uncertainty. In the Goor-project, delay did not influence any other uncertainty source. Thus, the decision whether to take action or to wait is influenced by the interaction between the factor 'time' and the uncertainty sources. Since negative interactions between the factor 'time' and the uncertainty sources were absent in the Goor-project, the 'postpone' strategy was effective in terms of dealing with perceived uncertainty. Apart from the differences with respect to political uncertainty, the projects in Sittard and Goor also have some similarities. In both project, the perceived uncertainties of investors negatively influenced the uncertainty which entrepreneurs themselves perceived about the mobilization of financial resources. The entrepreneurs of the Goor-project managed to reduce uncertainty about financial resources by influencing the investors' perceptions. A final similarity is that the projects in Goor and Sittard as well as the Cuijk-project show that technological problems not necessarily lead to an increase of perceived technological uncertainty. In the Goor-project, the perception of technological uncertainty was not affected by the occurrence of technological problems because the entrepreneurs had anticipated that teething problems were bound to happen. In short, the entrepreneurs of the Goor-project successfully applied different strategies for dealing with perceived uncertainties during the start-up stage. This reduction of perceived uncertainties motivated the entrepreneurs to continue with the project by proceeding to the implementation stage. Since then, the continuation of the project has not been endangered because perceived uncertainties remained low despite some technological problems.

6.4.2 The implementation stage

The project analysis continues with the projects which are, at the moment of writing, still in the implementation stage (see Figure 6-1). The projects are described in the order in which the projects entered the implementation stage.

Hengelo

Encouraged by the governmental waste management policy[16], waste processing company Twence developed a plan to convert waste wood into renewable electricity. Initially, in 2003, the idea was to build a stand-alone biomass gasification plant on their industrial site. However, based on disappointing results of a biomass gasification project in which Twence took part[17] and consultation of several engineering firms, Twence soon realized that this technology involved much uncertainty as it was still in a premature stage of development. Since biomass combustion technology was considered to be a 'proven technology' which involved less technological uncertainty, Twence decided to opt for combustion instead. (Rooijakkers and Dijkman 2006)

A study was carried out to determine the optimal scale of the project. In order to profit from economies of scale, a large-scale plant for conversion of 140.000 tons biomass per year was considered to be the best option. Twence already possessed part of this biomass input, but the remaining part had to be contracted from external biomass-suppliers. Because of Twence's experience in the biomass market, uncertainty about the availability and price for biomass or about the reliability of biomass-suppliers was not considered as a major problem. (Rooijakkers and Dijkman 2006)

However, uncertainty about technology suppliers did form a problem in the start-up stage of the project. Since Twence did not want to bear all the risks of the project alone, Twence was looking for a reliable technology developer who would deliver the plant as turnkey (meaning that one technology supplier is responsible for coordination of the construction activities and cooperation between the sub-contractors and that the risks of technological failures lie with this technology developer). Finding a technology supplier who was willing to accept these conditions appeared to be more difficult than expected. As hardly any suppliers had reacted to the call for tenders, Twence perceived great uncertainty if and when they would be able to find a technology supplier. In order to deal with this uncertainty, Twence approached several technology suppliers in order to persuade them to quote for the job. Finally, after some delay, Twence managed to close a contract with an experienced technology supplier from Germany (Standardkessel) and thereby reduced supplier uncertainty. (Rooijakkers and Dijkman 2006)

Before the final investment decision would be made, the largest source of perceived uncertainty, political uncertainty, still had to be reduced. Obtaining subsidy for the production of renewable electricity (MEP) was an absolute precondition for the project. Twence perceived great uncertainty about this issue, since the Dutch government had frequently altered the subsidy policy for renewable electricity over the past few years. One of the more recent changes was that a request for MEP-subsidy could not be submitted before all the necessary licenses were obtained. As a result, uncertainty about financial support from the government became intertwined with uncertainty about the duration and outcome of the licensing procedure. Since objections to the license could seriously delay the licensing procedure, and thereby delay the subsidy-request, Twence attempted to reduce uncertainty about the licensing procedure by negotiating with environmental organizations. In order to prevent objections, Twence came to an agreement with the environmental organizations that the installation would comply with stricter emission rules than governmental policy required. Not before both the necessary licenses and a 10-year MEP-subsidy were obtained, Twence decided to go ahead with implementation of the plant. (Rooijakkers and Dijkman 2006)

Construction of the plant started in April 2006. Thus far, construction has been proceeding according to plan and no new uncertainties have emerged. Since the project had obtained a MEP-subsidy, the most important source of perceived uncertainty hindering entrepreneurial action had been reduced. Nevertheless, the MEP-policy did influence the project in an indirect manner. Namely, under the current MEP-policy, it is economically more attractive to produce renewable electricity than to produce heat.[18] Moreover, in order to deliver heat to local residential areas and offices, Twence has to invest in the construction of a heat infrastructure. Twence wanted to finance this investment with the MEP-subsidy that Twence expected to obtain for another renewable electricity project. However, as the government suddenly cancelled the MEP-instrument in August 2006, Twence could no longer apply for a MEP-subsidy for this new project. As a result, Twence decided to postpone the construction of a heat infrastructure. (Rooijakkers and Dijkman 2006; Twence 2006) The biomass combustion plant is expected to produce its first electricity at the end of 2007.

Thus, during the start-up stage, the entrepreneur encountered several sources of perceived uncertainty. By performing feasibility studies and closing cooperation contracts with suppliers, the entrepreneur was able to reduce many of these perceived uncertainties. However, the reduction of political uncertainty was more complex, since two types of political uncertainty reinforced each other in a negative way under the influence of external factors. Due to institutional changes (i.e. adjustments to the MEP-instrument), a negative interaction emerged between uncertainty about the MEP-subsidy and uncertainty about the duration and outcome of the license procedure. The factor 'temporal duration' played an important role in this negative interaction, since one of these uncertainties (i.e. uncertainty about the license procedure) was causing a delay and the other (i.e. uncertainty about the MEP-subsidy) was increased by this delay. As a result, the entrepreneur had to eliminate uncertainty about the license in order to minimize uncertainty about the MEP-subsidy. The lobbying activities which the entrepreneur initiated to gain the support of environmental organizations and speed-up the license procedure were effective, since political uncertainty reduced. Thus, the activities that the entrepreneur initiated in the start-up stage helped to reduce perceived uncertainties. The reduction of perceived uncertainties, in turn, stimulated the entrepreneur to continue with the project by proceeding to the implementation stage.

Alkmaar

Waste processing company HVC in Alkmaar was delivering waste wood to a biomass combustion plant in Germany. In 2004, HVC initiated the plan to build a biomass combustion plant of one's own to convert waste wood into renewable electricity. A feasibility study was carried out to determine the optimal location of the plant, to analyse the availability and quality of biomass resources and to investigate which technologies were most suitable. Biomass gasification was considered to be still in a premature phase of development, due to the many technological problems of the only large-scale biomass gasification plant in the Netherlands (the Amer-project). HVC decided to build an identical biomass combustion plant as their German partners, since visits to several projects in Germany had proven that this technology functioned-well. Therefore, technological uncertainty was perceived to be small. In addition, uncertainty about technology suppliers was perceived to be small as German suppliers had much experience with the construction of biomass combustion plants and HVC did not encounter problems in finding reliable technology suppliers to deliver the technological components of the plant.[19] However, uncertainty about the availability of biomass resources was perceived to be large, as the demand for biomass was exceeding the supply. Although HVC already possessed part of the required waste wood streams, still a substantial part had to be bought on the market. In order to prevent biomass suppliers from breaking the contract if they could earn more money by delivering biomass to the competition, HVC decided to close 10-year contracts which guaranteed a fixed amount of waste wood delivery for flexible, market-conform prices. In this way, uncertainty about the long-term availability of biomass and uncertainty about the reliability of biomass-suppliers was reduced to a minimum. Uncertainty about the mobilization of financial resources to support the project was eliminated as well, since three banks decided to invest in the project.

However, a very important source of uncertainty threatening the final investment decision was political uncertainty. An absolute precondition for the project was the acquisition of a 10-year subsidy for the production of renewable electricity (MEP-subsidy). Without this subsidy, the project was economically unfeasible (HVC Alkmaar 2005; Van Lieshout 2006). Due to the frequent changes of the MEP-instrument, making it more and more difficult for entrepreneurs to receive a subsidy, HVC expected that there was a big chance that the Dutch government would cancel the entire MEP-instrument in the near future. In order to anticipate this policy change, HVC strived at speeding-up the start-up stage in order to acquire a MEP-subsidy before it might be too late. As we explained above, in the description of the Hengelo-project, uncertainty about the acquisition of a MEP-subsidy was intertwined to uncertainty about the licensing procedure. Just like Twence, HVC attempted to reduce uncertainty about the duration and outcome of the licensing procedure by negotiating with environmental organizations. In order to prevent objections, HVC came to an agreement with the environmental organizations that the installation would comply with stricter emission rules than governmental policy required. The strategy seemed to pay off. HVC managed to complete the licensing procedure within half a year, without any objections from environmental organizations. In June 2006, HVC obtained a permanent license and thereafter successfully applied for a 10-year MEP-subsidy. HVC had been just in time, since the MEP-instrument was indeed cancelled in August 2006. (Van Lieshout 2006) Thus, the activities that HVC undertook helped to reduce the most dominant sources of perceived uncertainty (resource uncertainty and political uncertainty) to an acceptable level. Construction of the plant started in July 2006. The plant is expected to be operational in December 2007 (HVC Alkmaar 2007).

In terms of interaction patterns, the Alkmaar-project is identical to the Hengelo-project. In both projects, the changes of the MEP-instrument created a negative interaction between uncertainty about the MEP-subsidy and uncertainty about the license procedure. Just like in the Hengelo-project, the activities that the entrepreneur of this project undertook during the start-up stage were successful to reduce the perceived uncertainties to an acceptable level. As a result, the entrepreneur decided to continue with the project and proceed to the implementation stage.

Moerdijk

The world's first large-scale CHP plant for the combustion of poultry manure was established in England in 1992. Inspired by the English example, Mestac (a cooperation of Dutch farmers which was established to find solutions for the disposal of manure) initiated the plan to build a similar plant in the Netherlands. By converting poultry manure into energy, the project would serve to decrease the Dutch manure surplus[20] while simultaneously contributing to the production of renewable energy. Even more, the ashes that would be produced in the combustion process could be used to produce fertilizer. (Munsters 2006)

In 1997, Mestac hired a technical consultancy firm to perform a feasibility study for the implementation of a poultry manure combustion plant in the Netherlands. The study indicated that the project would only be feasible if the following conditions were met: the scale of the project had to be at least 200.000 tons of manure per year, farmers had to be willing to pay *ƒ*25 (about 11 Euros) per ton for manure disposal and the project had to receive a subsidy for the production of renewable electricity. Because of the extensive feasibility study and the success of the manure combustion projects in England, technological uncertainty was perceived to be low. Although the application for poultry manure was still relatively new, combustion technology was considered to be a 'proven technology'. (Munsters 2006)

The main uncertainty that Mestac perceived in this stage of the project, was uncertainty about the supply of biomass resources. Although there was more than enough manure available in the Netherlands, the project could only be successful if a sufficient percentage of farmers was willing to commit themselves to the Mestac-project instead of choosing for other manure disposal initiatives. In the past, a Dutch manure disposal project ("Promest", a factory for the large-scale conversion of manure into fertilizer) had failed because the supply of manure was insufficient to make the project profitable (Eindhovens Dagblad 1996; Van Miltenburg 2003; Didde 2004). The lesson that Mestac had learned from this unsuccessful project, was that uncertainty regarding the long-term supply of biomass could endanger the success of the manure combustion project. Therefore, Mestac decided that the project would only continue if this uncertainty was reduced by the acquisition of long-term manure disposal contracts with farmers. In 1998, Mestac had managed to secure the long-term supply of 300.000 tons of manure per year and decided to go through with the project. (Munsters 2006)

Since also farmers outside of the Mestac cooperation wanted to deliver manure to the future combustion plant, the project activities were placed in the newly established DEP[21] foundation. The first activity of the DEP foundation was to establish partnerships among energy companies in order to ensure that there was a market for the energy produced with manure combustion and to mobilize financial resources for the project. Energy companies PNEM and EPZ were enthusiastic about the plans and decided to participate in the project. The energy companies agreed to co-finance the project and to sell the electricity produced by the manure combustion plant to their customers. The plant would be located at the site of EPZ in Moerdijk and was expected to be operational in 2002. (De Wit 1998; Van Miltenburg 1999)

However, environmental organizations were less enthusiastic about the plans. They believed that the Dutch government could better solve the manure surplus problem by stimulating a reduction of poultry at Dutch farms instead of supporting poultry manure combustion. Furthermore, environmental organizations argued that the combustion of manure would lead to excessive NO_x-emissions. (Van Miltenburg 1999; Dagblad voor Zuidwest-Nederland 2000; Didde 2000; ANP 2000b) To prevent objections to the license, DEP agreed to invest in additional gas-cleaning technology for the reduction of NO_x-emissions. Nevertheless, the environmental organizations filed an objection against the license. Their attempt to hinder the project was unsuccessful, as the Council of State[22] decided to reject the objections and, consequently, to grant an irrevocable license to the Moerdijk-project. (Munsters 2006)

Although the opposition of the environmental organizations did not obstruct the license-application, the protests did influence the project in another way. Namely, the protests of the environmental organizations led to a public debate about the question whether or not electricity produced out of poultry manure could be classified as 'renewable electricity'. The Dutch government did consider the energy from manure combustion to be 'renewable electricity' (ANP 2000b). However, energy company Essent (successor of energy companies EPZ and PNEM[23]) did not want to defend the Moerdijk-project to their customers and decided to withdraw from the project. (Munsters 2006; Savelkouls 2007) The withdrawal of Essent was a set-back to the entrepreneur, since Essent not only guaranteed certainty about the sale of electricity, but also co-financed the project.

DEP did not give up and decided to search for new investment partners. The English company EPR (Energy Power Resources, a company that invests in renewable energy projects) decided to join the project. However, also EPR withdrew from the project. One of the reasons for this was that the entrepreneurs perceived great uncertainty about the introduction of a new financial policy instrument (the MEP-instrument). Since the government had delayed the introduction of this new instrument, the entrepreneurs were uncertain if and when this new instrument would come into force. Because of this political uncertainty, the final investment decision was being postponed. As EPR's interests started to shift over time, they decided to drop out. (Munsters 2006) The exit of EPR led to an increase of uncertainty about financial resources and additional delays, as DEP again had to search for partners who were willing to invest in the project.

Fortunately, engineering company Siemens was willing to cooperate. As both DEP and Siemens did not have any expertise in the energy market, the search for a partner among the Dutch energy companies continued. This time, energy company Nuon expressed its interest in the project. However, cooperation problems reoccurred. In 2004, the negotiations were in an advanced stage when Nuon cancelled the deal because of a reorganization. (Munsters 2006; Savelkouls 2007)

The many changes in the actor constitution had repeatedly led to delays of the project. As a result, the budget of the project was exceeded. DEP perceived great uncertainty if they were able to mobilize financial resources and seriously doubted whether or not they should continue their endeavours to find partners who were actually willing to commit themselves to the project. (Munsters 2006)

To make things worse, the financial outlook of the project had changed because of the new financial policy instrument (MEP) which had come into force in 2003. Since the MEP-subsidy that the project had acquired for the production of renewable electricity was valid for a 10-year period, the investment costs had to be recovered within these 10 years. This meant that DEP had to increase the manure disposal price of the combustion plant. Consequently, the contracts that farmers had signed for the delivery of manure to the combustion plant were no longer valid. Thus, due to the long duration of the start-up stage, uncertainty about biomass resources increased again. (Munsters 2006)

Because the project had been delayed several times already, DEP decided to concentrate on searching new partners and arranging the finance of the project before again approaching farmers in order to conclude manure disposal contracts. In 2004, DEP entered into negotiation with energy company Delta and, a year later, cooperation was finalized (De Brie 2005a; De Brie 2005b).

As a result of the long duration of the start-up stage and the changing context, adjustments had been made to the original project plan. Namely, the capacity of the plant was increased to 400.000 ton manure per year. Furthermore, in reaction to uncertainty about biomass resources, the technical design of the installation was changed so as to be able to combust a range of biomass streams instead of being solely dependent on poultry manure. Since the original license which had been granted in 2002 did not include these changes, DEP applied for a revision license. However, environmental organizations again objected and requested that the revision license would be suspended (De Dordtenaar 2005). The Council of State granted the request and suspended the revision license until a final verdict would be given. Because the original license was still valid, the project activities were not delayed this time. Nevertheless, DEP's perception of political uncertainty increased as a rejection of the revision license would endanger the project's chance of success. (Munsters 2006)

In the meantime, DEP approached several banks in order to obtain a loan. Many banks were reluctant to invest in the project, as they perceived large uncertainties with respect to the project (i.e. technological uncertainty, uncertainty about biomass resources[24] and uncertainty about the license). Consequently, DEP perceived great uncertainty about the mobilization of financial resources (Munsters 2006; Van Ommen 2006). Finally, the NIB Capital Bank was willing to invest in the project if several conditions were met. One of the conditions was that DEP needed to contract at least 340.000 tons of manure so as to reduce the bank's perceived uncertainty about biomass resources. Therefore, DEP approached Dutch farmers to again ask for their commitment. Although some farmers were still very enthusiastic about the project, others were more sceptical. Because the project had been postponed several times already, faith in the realization of the project had diminished over time (Vermaas 2005b). Nevertheless, at the end of 2005, DEP had managed to acquire sufficient contracts to comply with the condition of the bank (Van Miltenburg 2005). More than 600 farmers will together deliver circa 400.000 tons of manure per year (Vermaas 2006a; Vermaas 2006c).[25] Another condition of the bank was that the key-actors involved in the development and implementation of the project should all become shareholder. In 2006, energy company DELTA, DEP, ZLTO (Zuidelijke Land- en Tuinbouworganisatie, an industrial organization for agriculture and horticulture in the south of the Netherlands) and AE&E (Austrian Energy & Environment, the technology developer which delivered the main components of the installation[26]) jointly founded the new corporation 'BMC Moerdijk BV'.[27] Thus, the entrepreneurs finally managed to reduce resource uncertainty. (Munsters 2006) In Augustus 2006, more than 8 years after the start of the project, construction of the plant started at last. However, while most of the uncertainties that DEP perceived had finally diminished, political uncertainty lasted. Namely, at the moment of the interviews (October 2006), the Council of State had not yet given a final verdict concerning the revision license. As a result, political uncertainty remained an important threat for the project's success. The plant is expected to be operational in May 2008. (Munsters 2006; Vermaas 2006b; Vermaas 2006d)

The Moerdijk-project probably gives one of the most visible examples of a negative interaction pattern. This negative interaction pattern was triggered by the resistance of environmental organizations against manure combustion. This external resistance resulted in an increase of political uncertainty (uncertainty about the license procedure) and changes in the actor constitution (withdrawal of energy company Essent). The changes in the actor constitution, in turn, resulted in an increase of consumer uncertainty and uncertainty about the mobilization of financial resources. Thus, the negative influence of external resistance had resulted in an accumulation of perceived uncertainties. In order to reduce the perceived uncertainties, the entrepreneur aimed at closing new cooperation agreements with energy companies and investment partners. Although a new investment partner was found in the English company EPR, the project was delayed. In the meantime, the institutional setting was changing and political uncertainty further increased. Apart from uncertainty about the license procedure, the entrepreneur now also perceived uncertainty about the introduction of a new financial instrument. In reaction to this increase of political uncertainty, the final investment decision was postponed and the project was further delayed. Because of the delay, EPR started to lose interest and decided to drop out. Thus, the actor constitution changed for the second time. The negative interaction pattern started to repeat itself since perceived uncertainties increased again and the search for new partners delayed the project even further. This negative interaction pattern repeated itself once more when energy company Nuon pulled back from the project. Despite the attempts of the entrepreneur to reduce perceived uncertainties (political uncertainty, resource uncertainty and consumer uncertainty), the entrepreneur was unable to break the negative interaction pattern. An important reason for this, is that the entrepreneur had not succeeded in gaining support from the environmental organizations. Thus, the external factor which had triggered the emergence of the negative interaction pattern continued to exist. Nevertheless, the entrepreneur remains motivated to continue his activities. The motivation was mainly based on beliefs: the entrepreneur had faith in the technology and kept believing in the opportunities that manure combustion had to offer.

6.4.3 The start-up stage

The only biomass combustion project that is currently still in the start-up stage, is the project in Apeldoorn (see Figure 6-1).

Apeldoorn

The biomass combustion project in Apeldoorn started many years ago, in 1997. Paes (a Dutch mineral resource company) became interested in the production of renewable energy out of biomass. Poultry manure was considered to be an attractive feedstock because it was widely available. Converting manure into energy would not only contribute to the goal of increasing the production of renewable energy, but also contribute to the manure disposal problem. Paes started searching for partners among technology developers and contacted FibroWatt, an English technology developer who had successfully implemented three poultry litter combustion plants in England. The two partners established a joint venture named 'Fibroned', with the goal of implementing a large-scale plant for the production of renewable energy out of poultry manure. In the following years, feasibility studies were carried out and several conversion technologies were examined. Gasification was considered too risky, as the technology was still in an immature stage of development and the entrepreneurs did not have any knowledge about this technology. Due to the large scale of the project, digestion was not judged as a good alternative either. Since the manure combustion plants of Fibrowatt in England were functioning well, the entrepreneurs were most confident about the development of a manure combustion plant. (Hermans 2006)

Although the entrepreneurs themselves barely perceived uncertainty about the technology, banks and other investors perceived greater uncertainty about the newness of manure combustion technology. In order to influence the investors' perception of technological uncertainty, Fibroned provided detailed information about the performance of the English manure combustion plants. These activities helped to reduce the perceived uncertainties of the investors. (Hermans 2006) Furthermore, Fibroned had signed 10-year manure-delivery contracts with farmers in order to reduce uncertainty about the supply of biomass. Uncertainty about the market for heat was reduced by the participation of energy company Nuon. Nuon agreed to construct a new heat infrastructure in order to supply the produced heat to nearby residential areas.

In February 2002, the financing of the project was arranged. Furthermore, the Province (the local authority responsible for granting the license) had given all the licenses that were necessary for the construction and implementation of the manure combustion plant. Construction of the plant was about to start. (Roelants 2002; Van Alem 2003) The plant would be located at an industrial site in Apeldoorn. The local municipality was very enthusiastic about the renewable and environmental-friendly character of the manure combustion plant and supported the project (ANP 2000a; Roelants 2002). However, neighbouring people and environmental organizations were less enthusiastic about the project and objected to the license. Although the Province initially rejected the objections, the Council of State decided to revoke the license due to procedural mistakes of the Province. (Gelders Dagblad 2003; Leeflang 2003; Hermans 2006) As a result, Fibroned had to restart the licensing procedure which led to great political uncertainty and serious delay of the project.

Two years later, in February 2004, Fibroned obtained a new license from the Province (Veluws Dagblad 2004a). However, despite attempts of Fibroned to come to an agreement with their opponents, environmental organizations and neighbouring people again objected to the license. Both parties adduced different and often contradictory arguments to proof their standpoint (Van 't Veen 2003). The Council of State decided to suspend the new license in order to have sufficient time to examine the case in-depth and give a final verdict (Veluws Dagblad 2004b). Because construction of the plant could not start while the license was suspended, the project was again delayed. Due to these delays, the costs of the project were running high. In addition, energy company Nuon withdrew from the project. Due to the uncertainty that Nuon perceived regarding if and when the Fibroned-plant would be operational, Nuon was unwilling to invest in the construction of a heat infrastructure (Apeldoornse Courant 2004). This, in turn, created uncertainty for Fibroned about the market for heat. Since the plant was primarily aimed at producing electricity, Fibroned decided to continue despite the withdrawal of Nuon. However, a new heat-consumer still had to be found. Thus, uncertainty about the licensing procedure had led to an accumulation of perceived uncertainties.

In October 2004, the independent expert committee (Stichting Advisering Bestuursrechtspraak, StAB) which had examined the Fibroned-case report to the Council of State and rejected practically all the objections which had been filed against the license (Van 't Veen 2004). Usually, the Council of State adopts the advice of this committee. Nevertheless, in March 2005, the Council of State decided to again revoke the license (ANP 2005; Van 't Veen 2005). Against all expectations, the Council of State classified the Fibroned-plant as a 'noise-polluting installation' (Agrarisch Dagblad 2005a). As the zoning plan of the industrial site in Apeldoorn did not allow for the establishment of this category of installations, the license was cancelled. (Vermaas 2005a; Agrarisch Dagblad 2005b; Agrarisch Dagblad 2005c; Hermans 2006) For the third time, the entrepreneurs of Fibroned encountered serious delay and perceived ever growing uncertainty about governmental policy. In addition, the new delay led to a further increase of the project's costs. Despite these setbacks, the entrepreneurs decided to continue with the project as they still believed in their plans. (Hermans 2006)

In order to manage uncertainty about the additional financial resources that were needed to compensate for the long duration of the licensing procedure, Fibroned received a loan from a local investment company (Apeldoornse Courant 2006a). At the moment of the interview, Fibroned was making preparations in order to again apply for a license. In April 2006, the minister of state decided to amend the law so that the Fibroned-plant would not be categorized as a noise-polluting installation (Severt 2006; Apeldoornse Courant 2006b). Although this amendment provides new opportunities for the Fibroned-project, the outcome of the licensing application remains uncertain as the opposition against the project perseveres (Agrarisch Dagblad 2006). Under the pressure of the public resistance, the initial support of the local municipality has diminished (Van 't Veen 2006). The Province, responsible for granting the license, has also become more reluctant because of the previous failures (Hermans 2006). And even if the license application would run smoothly, political uncertainty remains. Apart from uncertainty about the duration and outcome of the project, the Fibroned also perceived uncertainty about the financial policy of the government. During the long start-up stage of the project, several changes in the financial instrument had occurred: in 2003, the REB-instrument had been replaced by the MEP-instrument, in the following years several adjustments were made to the MEP-instrument and, in August 2006, the MEP-instrument was suddenly cancelled. For Fibroned and other renewable energy projects that were unable to obtain a MEP-subsidy, it remains to be seen what kind of financial support they may receive. (Hermans 2006) Thus, 10 years after the start, the project has still not entered the implementation stage. Despite the large political uncertainties, the entrepreneur remains confident about the future of the project. The reason for this, is that the entrepreneur still strongly believes in the business opportunities that manure combustion has to offer in terms of solving the manure disposal problem and increasing the production of renewable energy. (Savelkouls 2007)

In the manure combustion project in Apeldoorn, two negative interaction patterns can be identified. The first negative interaction pattern arose from the perceived uncertainty of banks. Banks were unwilling to invest in the Apeldoorn-project, because of the uncertainty they perceived about manure combustion technology. Hence, the perceived uncertainty of the banks negatively influenced the uncertainty which the entrepreneur perceived about the mobilization of financial resources. This negative interaction pattern was also encountered in the projects in Sittard and Goor. This negative interaction pattern did not have many consequences, since the uncertainties were reduced without causing big delays. However, the second negative interaction pattern was more severe. In resemblance to the manure combustion project in Moerdijk, this second interaction pattern was triggered by the resistance from environmental organizations and neighbouring people. Despite the attempts of the entrepreneur to come to an agreement with their opponents, the environmental organizations and neighbouring people continued to object to the license procedure. As a result of this resistance, political uncertainty strongly increased and the project was seriously delayed. This delay eventually resulted in the withdrawal of energy company Nuon, the increase of consumer uncertainty and resource uncertainty and the further increase of political uncertainty. Because the entrepreneur did not manage to gain support from the environmental organizations and neighbouring people, the negative interaction pattern continues to exist. Although the project has still not entered the implementation stage, the entrepreneur remains motivated to continue his activities. The motivation of the entrepreneur is mainly based on strong beliefs about the opportunities of manure combustion.

6.5 Interaction patterns

One of the goals of this chapter was to gain a better understanding of the emergence of negative and positive interaction patterns. To analyze what types of interaction patterns occur, the chronological project descriptions were used to identify causal relations between the different sources of perceived uncertainty, the various factors in the internal and external project environment, the motivation of the entrepreneurs, and the entrepreneurial actions. Although each project has evolved in its own specific way as a result of a unique combination of project-internal and project-external factors (e.g. specific actor constitution, institutional setting, etc.), several dominant interaction patterns were identified. The section below first describes the negative interaction patterns which were found in the biomass combustion projects. However, in most of the biomass combustion projects, negative interaction patterns either did not occur or only had a modest influence on the evolution of the project. The section therefore continues with several explanations for the continuation of the biomass combustion projects (in terms of the emergence of positive interaction patterns and the endurance or the absence of negative interaction patterns).

6.5.1 Negative interactions between different uncertainty sources

First, the project descriptions showed several examples of negative interactions between different sources of perceived uncertainty (see Table 6-3). In each of these examples, one source of perceived uncertainty directly or indirectly resulted in an increase of another source of perceived uncertainty.

As Table 6-3 shows, uncertainty about the mobilization of financial resources is frequently influenced by the uncertainties that investors perceive about the technology, the availability and price of biomass resources and/or governmental policy. Very often, the uncertainty perception of investors differs greatly from the uncertainty perception of entrepreneurs. Although entrepreneurs may not worry about a specific uncertainty source (such as technological uncertainty), this uncertainty source may be of such importance to investors that it discourages them from investing in entrepreneurial projects. The consequence of this negative interaction pattern is that entrepreneurs have to deal with the uncertainty perceptions of investors in order to reduce the uncertainty they themselves perceive about the mobilization of financial resources. Apart from such direct interactions between different uncertainty sources, Table 6-3 also gives several examples of indirect interactions. For instance, in the Lelystad-project, uncertainty about financial resources made the entrepreneur of this project experiment with cheaper biomass resources. These experiments were unsuccessful and resulted in technological problems, which in turn led to an increase of technological uncertainty. Thus, uncertainty about financial resources indirectly resulted in an increase of uncertainty about biomass resources.

Table 6-3 Examples of negative interactions between different uncertainty sources.

Interaction pattern	Project
Technological/political/biomass resources uncertainty of investor → financial resources uncertainty of entrepreneur	Sittard Goor Moerdijk Apeldoorn
Financial resources uncertainty → experimenting → technological problems → technological uncertainty	Lelystad
Political uncertainty → delay → consumer uncertainty	Sittard
Political uncertainty wrt license → delay → political uncertainty wrt MEP-subsidy	Hengelo Alkmaar
Technological uncertainty + uncertainty about knowledge resources → experimenting → delay → uncertainty about financial resources + biomass resources	Schijndel

Table 6-4 Examples of negative interactions between internal or external factors and perceived uncertainty.

Interaction pattern	Project
Social acceptance → change in actor constitution → consumer uncertainty + uncertainty about financial resources	Moerdijk
Institutional change → political uncertainty → delay → change in actor constitution → financial resources uncertainty	Moerdijk
Change in actor constitution + technological problems →technological uncertainty + uncertainty about technology suppliers + uncertainty about knowledge resources	De Lier
Change in actor constitution → uncertainty about knowledge resources + technology suppliers → knowledge-acquisition →delay → (institutional change →) uncertainty about financial resources*	Lelystad
Social acceptance → political uncertainty → delay → change in actor constitution → consumer uncertainty	Apeldoorn
Delay → institutional change → political uncertainty	Apeldoorn
Delay → institutional change → uncertainty about biomass resources	Moerdijk

* In Lelystad, delay both directly (via cost overrun) and indirectly (via institutional change, i.e. liberalisation of the energy market) resulted in an increase of uncertainty about the mobilization of financial resources.

6.5.2 The negative influence of internal and external factors

Second, the project descriptions showed that an increase of perceived uncertainty is often triggered or intensified by changes in internal or external factors in the project environment. Thus, negative interactions not only exist between different sources of uncertainty, but also between internal or external factors and perceived uncertainty (see Table 6-4).

Table 6-4 shows that the actor constitution, the institutional setting and the social environment (i.e. social acceptance of the project by environmental organizations and neighbouring people) are important factors influencing perceived uncertainties in the biomass combustion projects. Furthermore, the examples of Table 6-4 illustrate that internal or external factors can both directly and indirectly (by way of other factors) influence perceived uncertainties. For instance, in the Moerdijk-project (see Table 6-4), institutional change directly resulted in an increase of perceived uncertainty, whereas social acceptance indirectly (via a change in the actor constitution) influenced perceived uncertainty.

6.5.3 The importance of time in negative interaction patterns

A final remark with respect to Table 6-3 and Table 6-4 is that both tables prove that the time-factor (i.e. the temporal duration of a project, an internal factor) plays an important role in the development of negative interaction patterns. In the examples of Table 6-3, one source of uncertainty was resulting in a delay, which in turn was causing an increase of another source of uncertainty. For instance, in the Sittard-project, political uncertainty resulted in a delay of the project, which in turn caused an increase of consumer uncertainty. Similar interaction patterns are found in Schijndel, Hengelo and Alkmaar (see Table 6-3). The examples of Table 6-4 illustrate that the long duration of a project increases the chance that changes in the actor constitution (an internal factor) or in the institutional setting (an external factor) negatively influence the perception of uncertainties. This is clearly shown in the two manure combustion projects (Moerdijk and Apeldoorn). Because of their many delays, these projects were hindered by changes in the actor constitution as well as by institutional change (see Table 6-4). These changes, in turn, resulted in an increase of perceived uncertainties, which subsequently led to additional delays. In this way, negative interaction patterns started to build up over time.

6.5.4 Establishing positive interaction patterns

Although the biomass combustion projects displayed various negative interaction patterns, these patterns were not as dominant as the positive interaction patterns that were found between entrepreneurial action, perceived uncertainties and motivation. In these positive interaction patterns, the activities that the entrepreneurs initiated resulted in a reduction of perceived uncertainties, which in turn positively reinforced the motivation of the entrepreneurs to continue their actions.

Table 6-5 displays the various types of activities that have been initiated with the goal of reducing a specific source of uncertainty.[28] A distinction can be made between five types of activities: studying, experimenting, knowledge-acquisitioning, cooperating and lobbying. Lobbying activities were initiated to reduce perceived uncertainties that were caused by a lack of support from investors (i.e. uncertainty about the mobilization of financial resources), or from government and environmental organizations (i.e. political uncertainty). To deal with supplier uncertainty (uncertainty about the actions of technology or biomass suppliers), the entrepreneurs entered into long-term cooperation agreements. Another reason for entrepreneurs to enter into cooperation agreements was to gain access to technological knowledge, finances, biomass or customers in order to reduce technological uncertainty, resource uncertainty or consumer uncertainty. An activity that is related to cooperating is knowledge-acquisitioning. Whereas the cooperation agreements were mostly aimed at the long-term (e.g. the whole duration of the project), knowledge-acquisitioning was applied as a more 'ad hoc' strategy to reduce technological uncertainty and resource uncertainty. Two other related activities are studying and experimenting. Both of these activities aim to reduce perceived uncertainties (technological, resource or supplier uncertainty) by improving the knowledge base of the entrepreneur instead of acquiring knowledge by cooperation or knowledge-acquisition. As the project descriptions of the previous section show, studying activities are mostly applied in the start-up stage whereas experimenting activities are, logically, mostly applied during the implementation stage. As Table 6-5 shows, the entrepreneurs of the biomass combustion projects did not undertake specific activities to deal with uncertainty about the actions of competitors. The reason for this is that competitive uncertainty was not perceived to be an important source of uncertainty (see Table 6-2).

The various activities displayed in Table 6-5 were obviously not always successful. The above-mentioned example of the Lelystad-project (see Table 6-3) illustrated that the actions of the entrepreneurs occasionally resulted in an increase instead of a reduction of perceived uncertainties. Nevertheless, most of the times, these activities did succeed in reducing perceived uncertainties. This reduction of perceived uncertainties, in turn, positively influenced the motivation of entrepreneurs to continue their actions. In this way, positive interaction patterns between perceived uncertainties, motivation and entrepreneurial action were built up and negative interaction patterns were stopped or even prevented. Thus, the activities that the entrepreneurs initiated in reaction to perceived uncertainties form an important explanation for the fact that none of the projects was abandoned.

Table 6-5 Overview of the activities initiated to reduce perceived uncertainty.

Source of perceived uncertainty		Type of uncertainty-management activity	Project
Technological		Study activities: examining alternative technologies in order to select the technology of which perceived technological uncertainty is minimal, specifying the technical requirements of the installation for an optimal fit between the technological components and the project-specific characteristics	Cuijk Lelystad Sittard Goor Hengelo Alkmaar Moerdijk Apeldoorn De Lier 2
		Experimenting: making adjustments to the plant, learning which biomass streams best to use in the plant	De Lier 1 + 2 Schijndel Cuijk Lelystad Sittard Goor
		Knowledge acquisition: contracting technological experts	De Lier 1
		Cooperation: outsourcing the project to a turnkey technology supplier (i.e. the supplier had to accept the risks of technical failures)	Hengelo
Political		Lobbying: trying to gain support of governmental authorities, neighbouring people or environmental organizations (e.g. by organizing communication events or agreeing to comply with stricter emission rules than legally obliged in order to avoid objections to the license procedure)	Cuijk Goor Hengelo Alkmaar Moerdijk Apeldoorn
Resource	Biomass resources	Cooperation with biomass-supplier (often on the basis of long-term contracts)	Cuijk Lelystad Sittard Alkmaar Moerdijk Apeldoorn
		Study activities: e.g. analyze the biomass market in order to determine the availability, quality & price of the biomass stream, change the technical design of the future plant so as to be able to use a wide diversity of biomass streams	Sittard Cuijk Moerdijk
	Financial resources	Lobbying: trying to influence the perceptions of investors in order to gain financial support (e.g. by providing more information about the project and complying to the investors' terms)	Sittard Moerdijk Apeldoorn
		Cooperation with investment partners	Moerdijk Goor Alkmaar
		Experimenting: reducing costs by switching to cheaper, low-quality biomass	Lelystad
	Knowledge resources	Cooperation: outsourcing the project to a turn-key technology supplier	Lelystad
		Knowledge acquisition: contracting technological experts	De Lier 1 Lelystad

(Table 6-5 Continued)

Source of perceived uncertainty	Type of uncertainty-management activity	Project
Supplier	Study activities: selecting suppliers by means of an elaborate selection procedure	De Lier 2 Cuijk Lelystad Hengelo
	Experimenting: become independent of technology supplier by creating one's own knowledge base (learning-by-doing)	Lelystad
	Cooperation: i.e. by means of a special cooperation contract which guaranteed biomass-suppliers a market-conform price	Alkmaar
Competitive	*(no examples)*	-
Consumer	Cooperation with energy companies	Sittard Moerdijk Apeldoorn

De Lier 1 = first installation; De Lier 2 = second installation

6.5.5 The positive influence of internal and external factors

In Section 6.5.2, it was argued that negative interaction patterns are often triggered or intensified by internal or external factors in the project environment. However, the projects in Schijndel and De Lier show that external factors also play a role in the emergence of positive interaction patterns. In both these projects, external technological developments positively influenced the motivation of the entrepreneurs. Despite the technological problems encountered in their own projects, the entrepreneurs of these projects remained optimistic about biomass combustion technology. The reason for this was that the entrepreneurs had noticed that other wood combustion plants were functioning well. The success of these other wood combustion plants had such a strong influence on the motivation of the entrepreneur, that these positive external developments counteracted the negative results from the entrepreneurs' own experience. In addition, in the Schijndel-project, favourable institutional change (the introduction of the MEP-subsidy) positively influenced the motivation of the entrepreneur. Whereas Table 6-4 demonstrated that institutional change often results in an increase of perceived uncertainty, this project illustrates that institutional change might as well increase the motivation of entrepreneurs. Thus, external factors (such as external technological developments or institutional change) play an important role in negative interaction patterns as well as in positive interaction patterns. Although the empirical case did not provide clear examples of positive interaction patterns that were triggered by internal factors (like changes in the actor constitution), it is expected that internal factors also play a role in negative as well as positive interaction patterns.

6.5.6 The importance of perceived technological uncertainty

Apart from continuing entrepreneurial action because of successful uncertainty management activities, entrepreneurs may also decide to continue a project because the perceived uncertainties remain low. An interesting conclusion from Section 6.3 was that technological uncertainty was not perceived to be a dominant source of uncertainty, because entrepreneurs considered biomass combustion to be a 'proven technology'. However, despite the status of 'proven technology', technological problems were not absent. Looking at the project descriptions of Section 6.4, it becomes clear that most of the entrepreneurs were confronted with technological problems. The reason for this is that each project was still to a certain extent unique. Despite the fact that all the technical components were proven, the project descriptions clearly illustrated that the integration of these components into a successful-working installation is highly-dependent on project-specific characteristics. Due to differences in the biomass feedstock (e.g. differences in the degree of pollution or the moisture content) and differences in the application of the installation (e.g. the primary goal of the installation can be to produce electricity or to produce high-pressure steam for heating purposes), it was insufficient to simply duplicate the technical design of another successful-working biomass combustion plant. Furthermore, knowing that entrepreneurs of other projects had managed to develop and implement a successful-working installation did not alter the fact that the development and implementation of a biomass combustion plant was new to the Dutch entrepreneurs. This makes it even more interesting to conclude that technological uncertainty was not perceived to be a dominant source of uncertainty. In fact, the projects in Cuijk, Sittard and Goor show that technological problems not even have to result in an *increase* of perceived technological uncertainty. The entrepreneurs of these projects recognized that some time was needed in order to gain experience with biomass combustion technology and optimally adjust the installation to the project-specific characteristics. The technical problems that occurred were considered to be 'normal' teething problems that could be solved by a process of 'learning-by-doing'. Thus, despite the technical difficulties, technological uncertainty was not perceived to be a dominant source of uncertainty hindering the biomass combustion projects. The relatively low importance of technological uncertainty may very well have prevented the emergence of negative interaction patterns between technological uncertainty and the remaining uncertainty sources.

6.6 Conclusions

The aim of this chapter was to deepen our understanding of how perceived uncertainties influence entrepreneurial action, by analyzing what role perceived uncertainties have played in the development and implementation of biomass combustion installations in the Netherlands.

The empirical results showed that different sources of perceived uncertainty have played a role in the Dutch biomass combustion projects. The most important sources of perceived uncertainty influencing entrepreneurial decision-making were political uncertainty and resource uncertainty. Arguments for the importance of political uncertainty were first of all related to perceived uncertainty about the financial instruments for the production of renewable electricity. In addition, entrepreneurs considered political uncertainty as a dominant uncertainty source due to the uncertainty they perceived about the duration and outcome of the licensing procedure. The importance of resource uncertainty was primarily related to perceived uncertainty about the availability, price and quality of biomass resources. A second argument for the importance of resource uncertainty was that the entrepreneurs perceived uncertainty about the mobilization of financial resources (both from within the firm and from external investors).

Since interaction patterns between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action form an important explanation for the evolution of a project, this chapter specifically focused on the identification of different types of interaction patterns. In agreement with the findings of the previous chapter on biomass gasification, the dynamic project descriptions showed that perceptions of uncertainty change over time as a result of various interactions between different sources of uncertainty, factors in the internal or external project environment, and so on. Although each project has evolved in its own specific way as a result of a unique combination of internal and external factors in the project environment (e.g. specific actor constitution, institutional setting, etc.), several dominant interaction patterns were identified. These interactions can either have a negative or a positive influence on entrepreneurial action.

By analyzing the project descriptions, two types of negative interaction patterns were identified. First, negative interaction patterns occur between different sources of perceived uncertainty, meaning that one source of perceived uncertainty directly or indirectly result in an increase of another source of perceived uncertainty. Second, negative interactions occur between internal or external factors in the project environment and perceived uncertainty, meaning that changes in one of these factors directly or indirectly results in an increase of perceived uncertainty and/or a decline of the entrepreneur's motivation. Important factors influencing the biomass combustion projects were the actor constitution, the institutional setting and the social environment (i.e. social acceptance of the project by environmental organizations and neighbouring people). In both types of negative interaction patterns, the time-factor (i.e. temporal duration of a project, an internal factor) proved to play an important role. Delay of a project often directly or indirectly (via changes in the actor constitution or institutional setting) results in an increase of perceived uncertainties.

Although the project descriptions showed various examples of negative interaction patterns, none of the biomass combustion projects was abandoned. The empirical results gave several explanations for this. First of all, the project descriptions illustrated that entrepreneurs initiate various types of activities in order to reduce perceived uncertainties: studying, experimenting, knowledge-acquisitioning, cooperating and lobbying. Although these activities occasionally resulted in an increase instead of a decrease of perceived uncertainty, in most cases these activities succeeded in reducing perceived uncertainties. This reduction of perceived uncertainties, in turn, positively influenced the motivation of entrepreneurs to continue their actions. In this way, positive interaction patterns between perceived uncertainties, motivation and entrepreneurial action were built up.

The analysis furthermore showed that internal and external factors not only play a role in the emergence of negative interaction patterns, but also in the emergence of positive interaction patterns. Examples of external factors which had a positive influence on the continuation of entrepreneurial action are external technology development activities and favourable institutional change. Despite the technological problems that the entrepreneurs in De Lier and Schijndel encountered in their own projects, they decided to continue their actions because of the success of other wood combustion projects. Thus, external technological developments counteracted the negative results from the entrepreneurs' own experience.

Entrepreneurs may also decide to continue entrepreneurial action because their perception of uncertainties remains low. An interesting conclusion from the general overview of perceived uncertainties (Section 6.3) as well as the project descriptions (Section 6.4) is that perceived technological uncertainty did not play a dominant role in the biomass combustion case. The entrepreneurs considered biomass combustion to be a 'proven technology' because of the successful implementation of biomass combustion plants abroad. Nevertheless, most of the entrepreneurs of the biomass combustion projects were confronted with technological problems. The reason for this was that each project was still to a certain extent unique. Despite the fact that all the technological components were 'proven', the integration of these components into a successful working plant is highly-dependent on project-specific characteristics (such as the specific biomass characteristics). This makes it even more interesting to conclude that technological uncertainty was not perceived to be a dominant source of uncertainty, and that technological problems not even have to result in an increase of perceived technological uncertainty. The relatively low importance of perceived technological uncertainty may very well have prevented the emergence of negative interaction patterns between technological uncertainty and the remaining uncertainty sources.

Notes

1 This chapter focuses only on stand-alone biomass combustion projects for combined generation of heat and electricity. Co-firing of biomass in existing coal-fired power plants or biomass combustion plants which do not produce electricity (but only heat) are not taken into account.

2 Note that the data in this table is based on a broader definition of "biomass combustion CHP plants" than the definition that I apply in this chapter. Although the exact numbers depicted in the table may therefore slightly differ, the table does provide evidence for the general trend that the diffusion of biomass combustion technology is increasing.

3 A definition of the project stages (start-up, implementation and exploitation) can be found in Section 5.3.

4 Three of the twelve interviews were also used in the biomass gasification case, as these interviews focused on both biomass gasification and biomass combustion (see Appendix A). For the project in De Lier, we interviewed the consultant who was closely involved in the biomass combustion project and was well able to voice the vision of Mr De Lange. We also conducted a brief telephonic interview with Mr De Lange himself.

5 REB = Regulerende EnergieBelasting (Regulating Energy Tax)

6 MEP = regeling Milieukwaliteit ElektriciteitsProductie (Environmental quality of Electricity Production)

7 One of the interviewees expressed to perceive uncertainty about the assumptions that are made about future developments (e.g. about the future electricity price), which are used for determining the feasibility of a biomass combustion project. This uncertainty was not included in Table 6-1, since this uncertainty does not relate to the classification of uncertainty sources. As explained in Chapter 2 (Section 2.3), different classifications of uncertainty are possible. The uncertainty expressed here, relates to the 'nature of uncertainty' and can be classified as 'variability uncertainty (i.e. uncertainty that is inherent to changes of the environment).

8 England is frontrunner with respect to the implementation of poultry manure combustion plants. The other countries mentioned here are leading with respect to wood combustion plants.

9 Although the first wood combustion installation which Vyncke had implemented in the Netherlands was based on immature technology and therefore did not function optimally (see project-description of Schijndel), Vyncke had been able to learn from this experience and improve its technology over the years.

10 NeR = Nederlandse emissie Richtlijn voor lucht (Netherlands Emission Guidelines for Air)

11 PNEM was succeeded by Essent after the liberalization of the Dutch energy market in 1998. This change of actors did not have consequences for the project, as construction of the plant had already started and Essent did not change course with respect to his bio-energy activities.

12 As an experiment, Nuon, Staatsbosbeheer and several other organizations jointly developed an energy plantation which would deliver 10% of the biomass for the Lelystad-installation. Nuon decided to discontinue this experimental project in 2003, mainly due to economic reasons (Schiricke 2006). As the energy plantation

project did not have large impact on the developments of the biomass combustion project, we exclude it from the main storyline.

13 Integral green waste covers all material from landscape maintenance (grass, trimmings, wood residues, leaves, branches, etc.). Integral green waste can be characterized as low-quality biomass, due to its high moisture content, its variable composition and its relatively large pollution of sand, stones and so on. (Aarts 2006)

14 Since the data collection had already been finished, this incident did not affect the outcomes of this chapter.

15 Prior to this biomass combustion project, Bruins & Kwast had been involved in a biomass gasification project that terminated in the start-up stage (see Section 5.4.2 for a project-description).

16 As described in the 'National Waste Management Plan' (LAP= Landelijk AfvalbeheerPlan), which aims at encouraging waste prevention, waste recovery and optimisation of the use of the energy-content of non-reusable waste.

17 For a description of this project, see Chapter 5 (Section 5.4.2).

18 The MEP-subsidy only supports the production of renewable electricity. Bio-energy projects do not obtain financial support for producing heat.

19 In contrast to, for example, Twence (Hengelo-project), HVC did not choose for turnkey delivery of the plant, but coordinates the construction of the plant themselves.

20 In the mid 1980's, the manure surplus became an urgent problem in the Netherlands. (Negro 2007; Raven 2005)

21 DEP = Duurzame Energieproductie Pluimveehouderij; Sustainable Energy production Poultry Farming

22 The Council of State (in Dutch "Raad van State") is the highest administrative court in the Netherlands.

23 Due to the liberalization of the Dutch energy market, which was initialized in 1998, many energy companies had merged.

24 The banks' perception of uncertainty about the availability and quality of biomass resources (here: poultry manure) was intensified by the occurrence of an outbreak of avian influenza among poultry in the Netherlands in 2002, since such an outbreak led to a reduction of the total Dutch manure production. (Munsters 2006; Hermans 2006)

25 For purposes of comparison: 400.000 tons of manure accounts for a third of the total poultry manure production in the Netherlands.

26 Realization of the plant was outsourced to a consortium of Siemens and AE&E.

27 BMC= BioMassaCentrale (biomass plant).

28 Note that this table does not display all the activities of the entrepreneurs, but only those activities which have been initiated with the goal of reducing perceived uncertainties. For example, all entrepreneurs cooperated with technology suppliers, but only a few entrepreneurs mentioned cooperation as an activity which was initiated in reaction to perceived uncertainty.

7 Synthesis

7.1 Introduction

The goal of this final chapter is to synthesize the outcomes of the preceding chapters and to answer research questions 1, 2 and 3:

RQ1: *What are the dominant types of uncertainties as perceived by the various entrepreneurs involved in the development and implementation of micro-CHP, biofuels, biomass gasification and biomass combustion in the Netherlands?*

RQ2: *How do perceived uncertainties influence entrepreneurial action and thereby the development and implementation of these technologies?*

RQ3: *What general insights can be derived from the cases studied with respect to the influence of perceived uncertainty on entrepreneurial action in subsequent technology development phases?*

The chapter starts with a cross-case comparison (Section 7.2), discussing and explaining the differences and similarities between the cases with respect to the dominant types of perceived uncertainties, the type of actor fulfilling the role of entrepreneur and the influence of perceived uncertainties on entrepreneurial action. Thereupon, research questions 1 and 2 are answered and the research methodology which is used to answer these research questions is discussed. Section 7.3 discusses the general insights which can be derived from the empirical cases (research question 3).

7.2 Case comparison

In the previous empirical chapters, the influence of perceived uncertainties on entrepreneurial action was studied for four emerging energy technologies that are all considered to make an important contribution to the transition towards a more sustainable energy system in the Netherlands: micro-CHP, biofuels, biomass gasification and biomass combustion. The aim of this section is to discuss and explain the differences and similarities between the cases with respect to the dominant types of perceived uncertainties (Section 7.2.2), the type of actor fulfilling the role of entrepreneur (Section 7.2.3) and the influence of perceived uncertainties on entrepreneurial action (Section 7.2.4). The cross-case comparison focuses on three of the four case studies: micro-CHP, biomass gasification and biomass combustion. The reason for not including the biofuels case in the cross-case comparison is that the biofuels case was studied according to a different research protocol than the other cases. Since the aim of the biofuels case was to study how governmental policy influenced the perception of political uncertainty and the behaviour of the entrepreneurs involved, the biofuels case focused on only one source of uncertainty (i.e. political uncertainty). In addition, the data of the biofuels case was not based on interviews but on an extensive literature review. Due to this different research protocol, it is difficult to include the biofuels case in the cross-case comparison. Therefore, this section focuses on the comparison of the case studies on micro-CHP, biomass gasification and biomass combustion. However, in order to answer research question 1 and 2, the outcomes of the cross-case comparison are supplemented with the outcomes of the biofuels case (see Section 7.2.5). The section ends with a discussion of the research methodology which was used to answer these research questions (see Section 7.2.6).

7.2.1 Brief overview of the cases

As argued in Chapter 1, an important criterion for selecting the cases was that the cases focused on emerging energy technologies that are in different phases of development. The first technology development phase is the pre-development phase. According to the innovation literature (see Chapter 2), the pre-development phase is characterized by basic R&D activities in which various routes and options are suggested and tried (Van Lente, Smits et al. 2003). An indicator for the pre-development phase is that prototypes are being developed but the technology has not yet entered the market (see Chapter 1). The micro-CHP case focused on this phase (see Chapter 3). Combined generation of heat and power (CHP) means that heat and electricity are generated simultaneously. The application of CHP can lead to substantial energy savings and CO_x-emission reductions, since the overall efficiency is higher compared to generating space heating, hot water and electricity separately and, due to the decentralized production of electricity, distribution losses can be avoided. Up to now, CHP plants have been large-scale units for industrial processes. Recently, progress is made to apply CHP on domestic scale (i.e. installations with an electrical power below $5kW_e$). This application is called micro-CHP and is supposed to be a substitute for the high-efficiency boiler. In agreement with the theoretical description of the pre-development phase, technological variety in the development of micro-CHP was large. Various technology developers were working on competing micro-CHP systems. The most important competing micro-CHP technologies were the Stirling engine, the gas engine and the fuel cell. Since the first micro-CHP system still had to enter the market, end-users of the technology (i.e. house owners or tenants) had not yet taken account of the technology. Therefore, the group of potential adopters included in this case study consisted only of energy companies and housing organizations, as these actors play an important role in generating intermediary demand for micro-CHP systems and are already well informed about the development of micro-CHP (but not necessarily proponents of micro-CHP).

An indicator for the second phase of development, the take-off phase, is that the first adopters start buying and using the emerging technology (see Chapter 1). According to the innovation literature (see Chapter 2), the take-off phase is characterized by strong competition. Now that the new technology has entered the market, the technology has to compete with both established technologies and other new technologies (Utterback 1994; Van Lente, Smits et al. 2003). The case study that focused on this phase was the case on the development and implementation of biomass gasification (see Chapter 5). Gasification is a thermo-chemical process technology that converts biomass (usually wood residues, waste wood or manure) into a combustible gas. The produced gas (consisting mainly of CO and H_2) can be burned for heat or steam supply or it can be used in secondary conversion technologies (such as gas turbines or engines) to produce electricity. The advantage of gasification, is that much higher electrical efficiencies can be reached (35-40%) compared to combustion power plants (25-30%) (Williams and Larson 1996; Faaij, van Ree et al. 1997). However, gasification is technologically much more complex. Although this emerging technology can make a substantial contribution to the achievement of a more sustainable energy system, realization of biomass gasification projects often proves difficult and only a few projects in Europe have yet achieved a commercial status (Kwant and Knoef 2004; Faaij 2006). In the Netherlands, many activities to develop and implement this technology have been abandoned (Green Balance 2004; Van Ree, Beekes et al. 2005; Negro, Suurs et al. 2008). Of the seven biomass gasification projects described in Chapter 5, only one project is still on-going. As a result, the development of biomass gasification has (temporarily) stagnated in the take-off phase. The group of actors involved in these projects consists of technology developers and adopters (mostly energy companies, wood processing companies or farmers). For each of these projects, a dynamic analysis was performed to study the role of perceived uncertainties in various stages of the project (the start-up phase, the implementation phase and the exploitation phase).

The third phase is the acceleration phase: the phase in which the new technology becomes more and more embedded (see Chapter 2). The acceleration phase is indicated by a strong diffusion of the new technology (see Chapter 1). This phase was studied in the final case about biomass combustion (see Chapter 6). Biomass combustion is considered to be an appealing solution for achieving a more sustainable energy system, as it is a relatively simple technology to convert biomass into electricity and heat. In the combustion process, biomass (usually wood residues, waste wood or manure) is combusted to produce steam. The steam can be used for heating purposes and for the production of electricity (via a steam turbine). Although the electrical efficiency of biomass combustion is lower compared to other thermo-chemical conversion technologies (like gasification or pyrolysis), the main advantage of biomass combustion is that the technology is in a more mature stage of development compared to the other technologies (Energie- en Milieuspectrum 1997; BTG 2005; IEA Bioenergy 2006). Over the past years, the number of operational biomass combustion plants and the installed (thermal and electrical) capacity have been steadily increasing. Of the ten Dutch biomass combustion projects described in Chapter 6, six projects have reached the exploitation stage and at least three more projects are expected to be operational in the near future (Junginger and Faaij 2005; Tijmensen and De Vos 2005; Daey Ouwens 2005b). Since biomass combustion and biomass gasification are rather similar technologies, the socio-institutional setting and the actors involved in the biomass combustion case were to a large extent identical to the biomass gasification case. The similarities in terms of types of actors and socio-institutional setting, combined with the contrasts in terms of phase of development and project outcomes make comparison of these two cases even more interesting.

7.2.2 The dominant sources of perceived uncertainty

In Chapter 2, a typology of uncertainty sources was introduced for analyzing perceptions of uncertainties concerning the development and implementation of emerging technologies: technological, resource, competitive, supplier, consumer, and political uncertainty. In this section, the three cases are compared with respect to the dominant sources of perceived uncertainty (research question 1).

In the micro-CHP case, the main sources of perceived uncertainty were technological uncertainty and political uncertainty. Arguments for the importance of technological uncertainty were all related to uncertainty about the future performance of micro-CHP systems. Since micro-CHP technology was still in the prototype-development stage, it was yet unknown what the future technological characteristics of the micro-CHP systems would be (in terms of efficiency, investment cost, life span, reliability, and so on), how the micro-CHP systems would operate in real-life situations, and how much time would still be needed in order for micro-CHP systems to become 'proven technology'. Arguments for the importance of political uncertainty had several causes. First of all, political uncertainty stemmed from the frequent changes in sustainable energy policy over the past years (especially the many changes to the financial instruments, REB and MEP). These frequent changes have resulted in perceived uncertainty about the reliability of the Dutch government in general. Second, the importance of political uncertainty was caused by perceived uncertainty about governmental support for micro-CHP, especially with respect to the electricity feed-in policy and the energy tax regime. Although micro-CHP systems are expected to enter the market soon, it was still uncertain whether the government would stimulate the creation of a market by means of a guaranteed minimum price for the electricity that micro-CHP owners fed into the grid. Furthermore, entrepreneurs still perceived uncertainty if the government would support the introduction of micro-CHP by making adjustments to the energy-tax regime. Under the current regime, micro-CHP users will have a cost disadvantage compared to non-users. Since both the electricity feed-in policy and the energy tax regime greatly influence the economic feasibility of micro-CHP systems, uncertainties about these aspects are of great importance to the introduction of micro-CHP.

The dominant sources of perceived uncertainty in the biomass gasification case, were technological, political and resource uncertainty. The main reason for the importance of technological uncertainty was the lack of previous experience with the technology, which created uncertainty about the performance of biomass gasification plants. Arguments for the importance of political uncertainty were mostly related to uncertainty about the licensing procedure and the emission regulation. The Dutch regulation with respect to the licensing procedure of bio-energy projects is very complex, partly overlapping and in some situations even conflicting. This has led to uncertainty about the interpretation of the law. Moreover, the complexity of the law offered many opportunities for neighbouring people and environmentalists to object to the license and thereby to delay or even obstruct the construction of a plant. As a result, the entrepreneurs perceived great uncertainty about the duration and outcome of the licensing procedure. This uncertainty is of great importance, since delay of the procedure, withdrawal of the license or the imposition of strict emission rules can have serious consequences for the profitability of a project. The second argument for the importance of political uncertainty was uncertainty about changes in the financial instruments (REB, MEP). The frequent and often unexpected changes of the financial instruments in the past not only resulted in uncertainty about future changes of these instruments, but also about the reliability of the Dutch government in general. The importance of resource uncertainty was first of all related to uncertainty about the availability, price and quality of biomass, since the market for biomass was relatively new and still unstable. The second argument for the importance of resource uncertainty was that the entrepreneurs perceived uncertainty about the mobilization of financial resources both within the firm and external to the firm (from banks and other investors). Investors were reluctant to invest in biomass gasification projects since biomass gasification was not yet a 'proven technology'.

In contrast to the micro-CHP case and the biomass gasification case, technological uncertainty did not play a dominant role in the biomass combustion case. The Dutch entrepreneurs considered biomass combustion to be a 'proven technology' due to the successful development and implementation of biomass combustion plants abroad. However, this did not imply that technological problems were absent. In fact, most of the entrepreneurs of the biomass combustion projects were confronted with technological problems. Despite the fact that all the technological components were 'proven', the integration of these components into a successful working biomass combustion plant proved to be highly-dependent on project-specific characteristics (such as the specific biomass characteristics). However, the biomass combustion case showed that such technological problems not necessarily have to result in an increase of perceived technological uncertainty. The reason for this is that most entrepreneurs recognized that some time was needed in order to gain experience with biomass combustion technology. The technical problems that occurred were considered to be 'normal' teething problems which could be solved by a process of 'learning-by-doing'. In the biomass combustion case, the main sources of perceived uncertainty were political uncertainty and resource uncertainty. The arguments for the importance of political uncertainty were similar to the biomass gasification case. That is, political uncertainty played a dominant role due to perceived uncertainty about (unexpected) changes in the financial instruments and about the outcome and duration of the licensing procedure. The similarities between the biomass gasification case and the biomass combustion case with respect to political uncertainty were to be expected, since the development and implementation of these biomass conversion technologies took place in the same institutional setting. The two biomass cases are also similar with respect to resource uncertainty. The importance of resource uncertainty was first of all related to perceived uncertainty about the availability, price and quality of biomass. Furthermore, resource uncertainty stemmed from perceived uncertainty about the mobilization of financial resources. Whereas the entrepreneurs perceived biomass combustion technology to be 'proven', investors were still hesitant to invest in biomass combustion projects. The uncertainties that investors perceived about the technology, the license procedure or the availability of biomass hindered them from investing in these projects.

The results of the cross-case comparison are summarized in Table 7-1. As Table 7-1 shows, the main sources of perceived uncertainty were political uncertainty, technological uncertainty and resource uncertainty. Political uncertainty was in all three cases a dominant source of perceived uncertainty. One of the main arguments for the high level of perceived political uncertainty in these cases, was uncertainty about (unexpected) changes in the financial instruments. The frequent changes of the financial instruments in the past not only resulted in uncertainty about future changes of these instruments, but also about the reliability of the Dutch government in general. Next to this, political uncertainty also stemmed from uncertainty about the effect of current policy. To some extent, perceived uncertainty about the licensing procedure in the biomass gasification and the biomass combustion case was comparable to perceived uncertainty about the energy tax regulation in the micro-CHP case. Namely, in both these examples of political uncertainty, the existing regulation hampered the introduction of the emerging technologies. The existing energy tax regime resulted in a cost disadvantage for micro-CHP users in comparison to non-users, whereas the ambiguity and overlap in the emission regulation with respect to the licensing procedure of bio-energy plants enabled opponents of bio-energy projects to delay or even obstruct the implementation of biomass gasification and biomass combustion

Table 7-1 Overview of the dominant sources of perceived uncertainty per case.

	Micro-CHP	Biomass gasification	Biomass combustion
Technological uncertainty	++	++	+
Resource uncertainty	+	++	++
Competitive uncertainty	+	+	+
Supplier uncertainty	+	+	+
Consumer uncertainty	+	+	+
Political uncertainty	++	++	++

++ = dominant uncertainty source, + = uncertainty source which is present but not dominant plants. In other words, institutional change is needed in order to adjust the regulatory setting in favour of the emerging technologies and thereby reduce the uncertainty that entrepreneurs perceive in not knowing what kind of regulations will emerge for the innovation (Van de Ven 1993; Jacobsson and Johnson 2000; Jacobsson and Bergek 2004).

As Table 7-1 furthermore shows, technological uncertainty was perceived to play a dominant role in the micro-CHP case and the biomass gasification case, since practical experience with these emerging technologies was still lacking. Perceived technological uncertainty was of minor importance in the biomass combustion case because the entrepreneurs considered biomass combustion to be a 'proven technology' due to the successful application of this technology abroad. This actor-level empirical finding is in line with the system-level theory which describes that technological uncertainty is high in the early 'formative' stages and decreases in later stages of market expansion (e.g. Tushman and Rosenkopf 1992; Afuah and Utterback 1997; Jacobsson and Bergek 2004).

The importance of resource uncertainty in the biomass gasification case and the biomass combustion case (see Table 7-1) was mainly related to feedstock and financial resources (and to a much lesser extent to knowledge resources). Resource uncertainty with respect to feedstock did not play a role for the micro-CHP systems (which are primarily fuelled by natural gas), but was very important for the two biomass technologies. Whereas the market for natural gas is a mature market with fixed quality standards and stable market prices, the market for biomass is still rather new. When the first biomass gasification and biomass combustion projects started (in the early 90's), biomass still had a negative market value (meaning that people had to pay for biomass disposal). In a few years time, the demand for biomass, and consequently also the market value of biomass, has increased rapidly. This has resulted in uncertainty about the availability and price of biomass. In addition, entrepreneurs have been perceiving uncertainty about the quality of biomass, since the quality of various biomass streams can differ greatly and quality standards are still lacking. Uncertainty about the mobilization of financial resources was also more important in the biomass cases than in the micro-CHP case. The dependency on external investors seems to play an important role in this. In the micro-CHP case, the technology developers were committed to engage in entrepreneurial activities and were willing to commit money to these activities. The mobilization of financial resources from within the firm seemed sufficient to cover the costs of the prototype-development phase. In the biomass cases, development and implementation projects were initiated. These projects were usually funded by multiple entrepreneurs, banks or other external investors. The mobilization of financial resources from external investors often proved to be difficult, as the uncertainties which these investors perceived made them reluctant to invest in the projects.

According to Table 7-1, the remaining uncertainty sources (supplier, consumer, competitive uncertainty) were perceived to be less important in the three empirical cases. But although these uncertainty sources were not very influential in general, they did play an important role for some individual actors or in some individual projects. In the micro-CHP case, for instance, technology developers were convinced that there was a market for micro-CHP and did not worry about consumer uncertainty whereas the remaining actors (potential adopters, government and an intermediary organization) perceived consumer uncertainty to be of much importance. In the biomass cases, the non-dominant uncertainty sources sometimes had great impact on individual projects. For example, supplier uncertainty was of major influence in the biomass gasification project at the Amercentrale and the biomass combustion project in Lelystad. Thus, it is necessary to include all six sources of perceived uncertainty into the analysis in order to be able to explain the behaviour of individual actors and the dynamics of individual projects.

7.2.3 The role of entrepreneur

One of the starting points of this thesis was that emerging technologies cannot break through without the involvement of entrepreneurs who are willing to take action under uncertainty. The role of the entrepreneur is to turn the potential of new knowledge, networks and markets into concrete actions to generate and take advantage of new business opportunities (Hekkert, Suurs et al. 2007). Whether or not different types of actors (i.e. technology developers or adopters) will fulfil this role of entrepreneur, is dependent on whether the actor is motivated enough to act given the uncertainty he or she expects to encounter in pursue of these business opportunities (McMullen and Shepherd 2006; Hekkert, Suurs et al. 2007; Meijer, Hekkert et al. 2007b). In this section, the three cases are compared with respect to which types of actor fulfilled the role of entrepreneur and what motivated these actors to take-on this entrepreneurial role.

In the micro-CHP case, the role of the entrepreneur was fulfilled by the technology developers. The motivation of the technology developers to become actively involved in the development of micro-CHP was strongly based on high expectations about the future market for micro-CHP systems. Due to the substantial energy savings and CO_x-emission reductions of generating heat and electricity simultaneously, technology developers strongly believed that micro-CHP systems are a good substitute for high-efficiency boilers. In addition, the Dutch market for micro-CHP systems is favoured by the dense gas infrastructure, the relatively cool climate and the tradition of decentralized cogeneration. Since technology developers strongly believed in the potential profit they could make by bringing a successful-working micro-CHP system to the market, they were willing to invest in technology development activities despite the uncertainties they perceived. On the contrary, potential adopters (energy companies and housing organizations who considered buying micro-CHP systems) were in this early phase far more reluctant and were unwilling to become actively involved in the development of micro-CHP. Instead, potential adopters followed a 'wait-and-see' strategy. In order to stay informed about the developments of micro-CHP and to express their interests, they undertook some low-cost activities like participating in a working group. However, potential adopters postponed large investments in the new technology until the uncertainties they perceived had been reduced by the actions of the technology developers.

In the biomass gasification case, the role of entrepreneur was fulfilled by technology developers and adopters (energy companies, wood processing companies or farmers) collectively. The motivation of both technology developers and adopters to become involved in the development and implementation of biomass gasification was based on high expectations about the opportunities that biomass gasification had to offer. Wood processing companies and farmers were interested in the application of biomass gasification technology to convert their waste streams (wood residues, waste wood or manure) into energy. The energy produced could be used within the company (to save energy costs) or sold on the energy market (as additional revenues). Energy companies were mainly driven by the governmental policies to reduce CO_x emissions and produce 'renewable' electricity. Biomass gasification was generally considered to be a promising technology, since the conversion efficiency of biomass into electricity is much higher compared to other technologies like biomass combustion or biomass digestion. For adopters, this meant that more energy could be produced with the same amount of biomass and, consequently, a higher turnover could be attained on the energy market. Because of the high electrical efficiency of biomass gasification in comparison to competing technologies, technology developers believed that there was a market for this technology. However, as the technology had just entered the market and the number of installed plants was still very limited, these high expectations were mainly based on desktop studies and personal beliefs instead of practical experience. This lack of practical experience formed an important reason for technology developers and adopters to cooperate and undertake entrepreneurial activities collectively. An advantage of joint entrepreneurship was that the partners could make use of each other's knowledge base in order to reduce the perceived uncertainties. Although biomass gasification technology had entered the market, the technology was not yet so mature that it could be sold as a 'turn-key' energy plant. Instead, the technology entered the market as a 'first-of-a-kind' product, which consisted of different components which had never before been integrated and which needed to be adapted to the specific circumstances at the location of application (e.g. adjustments to the characteristics of the feedstock). Therefore, both knowledge of the technology developer and knowledge of the adopter were needed in order to develop a successful working biomass gasification plant. Another reason for technology developers and adopters to cooperate is that these collective projects enabled technology developers to launch their product onto the market whereas adopters were offered the opportunity to implement this promising technology while sharing the risks with the technology developers.

Since biomass gasification and biomass combustion are rather similar technologies, the actors involved in the development and implementation of these technologies are to a large extent identical. Many of the technology developers who develop biomass gasification plants also develop biomass combustion plants. Furthermore, the technologies are adopted by the same type of actors (energy companies, wood processing companies, farmers) and some of these actors (i.e. energy company Essent, wood processing company Bruins & Kwast and waste processing company Twence) have been involved in biomass gasification projects as well as in biomass combustion projects. Nevertheless, the cases differed with respect to the role that these actors fulfilled and their motivation to do so. First, the motivation of adopters to fulfil the role of entrepreneur differed from the biomass gasification case. Although some of the adopters (mostly the owners of small and medium-sized companies) were strongly driven by enthusiasm about biomass combustion technology (i.e. 'emotional-based' motivation), most of the adopters had a more 'rational' motivation to engage in the development and implementation of biomass combustion plants. The latter type of entrepreneurs compared different bio-energy technologies (including gasification) and opted for biomass combustion in order to minimize perceived technological uncertainty. Based on the positive results from implementation projects abroad, these entrepreneurs considered biomass combustion to be a 'proven' technology with low technological uncertainties. Although the conversion efficiency of biomass combustion is lower compared to biomass gasification, the entrepreneurs preferred this 'proven' technology over a superior (in terms of electrical efficiency) but more-uncertain alternative like gasification.

A second difference is that technology developers played a far more modest role in the biomass combustion case as compared to the biomass gasification case. Apart from the project in Apeldoorn, which was a joint initiative of an adopter and a technology developer, all the biomass combustion projects were initiated by adopters alone. Technology developers were hired for the development and implementation of the biomass combustion plants, but were not involved as entrepreneurs (meaning that technology developers did not invest in the project and were not involved in the decision whether or not to continue with the project). Considering that biomass combustion plants were no ‘ready-made’ technologies, this modest role of the technology developers is remarkable. Just like in the biomass gasification case, the integration of the technological components into a successful working biomass combustion plant required knowledge of the adopter as well as of the technology developer. However, in contrast to the biomass gasification case, this requirement did not motivate the adopters of the biomass combustion case to share the entrepreneurial role with technology developers. This difference between the two cases can also be explained by the status of the technology. Because biomass combustion was perceived to be a ‘proven technology’, the need to share risks with technology developers was lower in the biomass combustion projects than in the biomass gasification projects.

In short, the type of actor fulfilling the role of entrepreneur shifts between the subsequent cases from technology developer (micro-CHP), via technology developer and adopter collectively (biomass gasification), to adopter (biomass combustion). The cases also differ with respect to the motivation of the entrepreneurs. In the first two cases (micro-CHP and biomass gasification), the motivation of the entrepreneurs to engage in the emerging technology was primarily based on enthusiasm and expectations instead of practical results (i.e. more ‘emotional’-based motivation). In the biomass combustion case, most entrepreneurs carefully explored different technological alternatives in order to opt for the technology with minimal technological uncertainties (i.e. more ‘rational’-based motivation).

7.2.4 The influence of perceived uncertainty on entrepreneurial action

In order to determine how perceived uncertainties affect the development of emerging energy technologies, this section compares the empirical findings of the three cases with respect to the influence of perceived uncertainties on entrepreneurial action (research question 2).

Analytical focus

Although all of the cases described how the various types of entrepreneurs reacted to the perceived uncertainties, the cases each had a slightly different analytical focus. The aim of the micro-CHP case was to analyze whether the reactions of technology developers and potential adopters to perceived uncertainty stimulate or hamper the overall transition process. An Innovation System approach was adopted to relate the behaviour of these actors to the transition process. The central idea behind the Innovation System approach is that actors do not innovate in isolation, but in the context of a system. This context is labelled the ‘(Technological) Innovation System’[1] and includes all elements (institutions, actors and networks) which contribute one way or another, directly or indirectly, intentionally or not, to the emergence of (technological) innovation. (Freeman and Lundvall 1988; Nelson 1988; Carlsson and Stanckiewicz 1991; Jacobsson and Johnson 2000; Hekkert, Suurs et al. 2007) Recently, innovation scholars have formulated a generic list of key activities that contribute to the success of transitions (the so-called ‘Functions of Innovation Systems’ or ‘System Functions’) (Johnson 2001; Jacobsson and Bergek 2004; Hekkert, Suurs et al. 2007; Negro 2007). These key activities include entrepreneurial activities (here very narrowly defined as experimental projects by entrepreneurs[2]), knowledge development, knowledge diffusion, guidance of the search (i.e. activities that can positively influence the visibility and clarity of specific needs among technology users and thereby guide the direction of technological development), market formation, resources mobilization and creation of legitimacy (i.e. lobbying activities which help to put the new technology on the

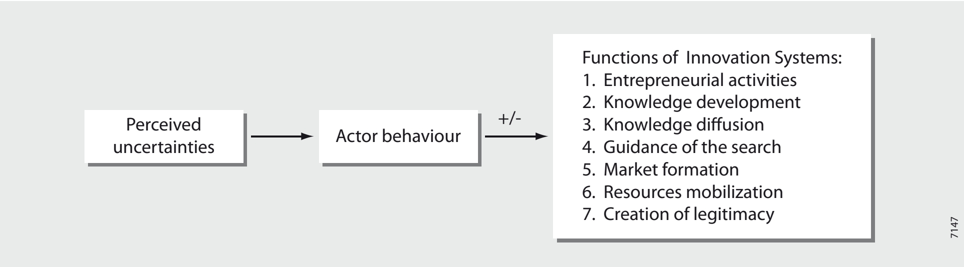

Figure 7-1 Conceptual model of the micro-CHP case.

agenda) (see Chapter 3, Section 2 for a more-detailed description). In order to gain more insight into the influence of perceived uncertainties on the overall transition, the micro-CHP case analyzed whether perceived uncertainties stimulated or hindered the actors from undertaking these key activities (see Figure 7-1).

The conceptual model applied in the micro-CHP case was useful for linking the behaviour of individual actors to the overall transition. However, not so much insight was gained into the underlying aspects which explain why some actors decide to take action under uncertainty whereas others do not. In order to analyze this in more detail, the cases on biomass gasification and biomass combustion zoomed in on development and implementation projects and applied a more complex conceptual model to examine the influence of perceived uncertainty on the actions of the entrepreneurs involved (see Figure 7-2). In this model, entrepreneurial action was more broadly defined than in the conceptual model displayed in Figure 7-1. Whereas the System Function 'entrepreneurial activities' only referred to the initiation of projects by entrepreneurs, the concept 'entrepreneurial action' of Figure 7-2 also referred to other types of activities which entrepreneurs involved in these projects undertake (like closing cooperation contracts with biomass-suppliers, mobilizing financial resources for the project, lobbying for governmental support, and so on). In order to gain a better understanding of the decision whether or not to act under uncertainty, more emphasis was placed on the *motivation* of entrepreneurs as being a counterbalance to perceived uncertainties (see inner core of Figure 7-2). In addition, it was argued that the decision of entrepreneurs whether or not to act does not take place in a vacuum, but is influenced by various *factors in the (internal and external) project environment* (see left-hand side of Figure 7-2). Furthermore, a dynamic perspective was added in order to analyze how perceived uncertainties, motivation and consequently the decision of entrepreneurs whether or

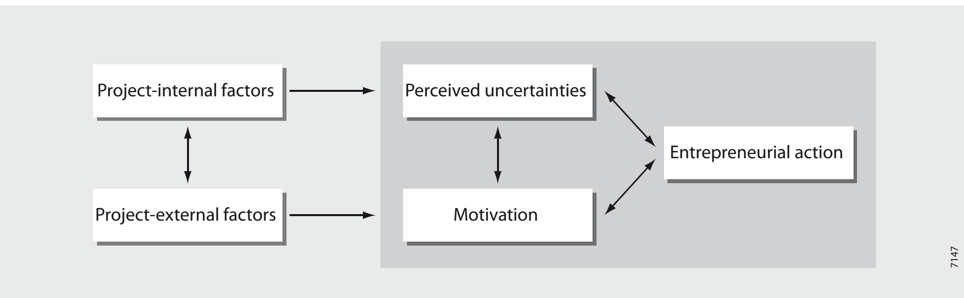

Figure 7-2 Conceptual model of the biomass gasification and the biomass combustion case.

not to act change over time under the influence of previous actions, changes in the internal or external factors, and so on (see double-sided arrows in Figure 7-2).

Empirical outcomes

As described above, the goal of the micro-CHP case was to analyze whether the reactions of technology developers and potential adopters to perceived uncertainty stimulate or hamper the overall transition process. This was done by analyzing whether perceived uncertainties stimulate or hinder these actors from undertaking certain key activities which are essential for achieving a transition (the so-called 'Functions of Innovation Systems', see Figure 7-1 and Section 3.3.2 of Chapter 3). The empirical results showed that technology developers and adopters reacted differently to perceived uncertainties. Whereas perceived uncertainties restrained potential adopters from acting entrepreneurially (see Section 7.2.3), perceived uncertainties did not hamper technology developers to fulfil the role of entrepreneur. For technology developers, perceived uncertainties formed an incentive to initiate all sorts of activities. These activities were aimed to manage the dominant sources of uncertainty. In reaction to technological uncertainty, technology developers invested in knowledge-development activities (Function 2 of Figure 7-1). In reaction to political uncertainty, technology developers initiated lobbying activities in order to create legitimacy for micro-CHP (Function 7 of Figure 7-1).[3] Since the fulfilment of these activities contributed to the functioning of the emerging technological innovation system and progress was still being made, it was concluded that, in this early phase of the transition process, perceived uncertainties did not hamper the development of micro-CHP.

The biomass gasification case and the biomass combustion case zoomed in on development and implementation projects. The specific goal of the biomass gasification case was to analyze how the decision of actors whether or not to act entrepreneurially under perceived uncertainty changes in different project stages (start-up, implementation and exploitation) and what factors in the project environment influence this decision. The dynamic analysis of the various biomass gasification projects proved that entrepreneurs will decide to act only if their motivation is strong enough to counterbalance perceived uncertainties. Furthermore, the analysis showed that perceived uncertainties and motivation change over time under the influence of various internal and external factors in the project environment (including, among others, changes in the actor constitution, institutional change and external technological developments). Whereas the motivation of the biomass gasification entrepreneurs was initially strong enough to outweigh perceived uncertainties, most of the biomass gasification projects were abandoned prematurely due to an increase in perceived uncertainties and/or a decrease in motivation. The termination of these projects can be explained by the frequent occurrence of negative interaction patterns between the various factors in the project environment, the different sources of perceived uncertainty and the motivation of the entrepreneurs. Due to the great diversity of factors and sources of perceived uncertainty, the project descriptions showed many different types of negative interaction patterns. An example, based on the biomass gasification project in Hengelo (see Chapter 5), is graphically represented in Figure 7-3. In this project, perceived technological uncertainty increased, since the development and implementation of a biomass gasification plant turned out to be more complicated than the entrepreneurs had expected. While the entrepreneurs tried to reduce technological uncertainty by experimenting with the technology, the project was more and more delayed and the costs were running high. As a result, uncertainty about the mobilization of financial resources increased. Due to the strict deadline which was imposed upon the project by the limited validity duration of the license[4], the delays also resulted in a decrease

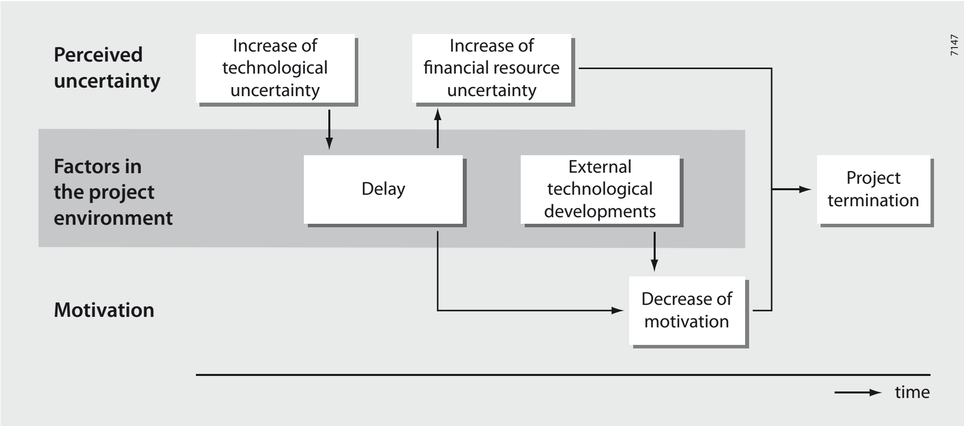

Figure 7-3 Schematic representation of a negative interaction pattern.

of the motivation of the entrepreneurs. In addition, external technological developments (i.e. the success of competing technologies) further decreased the motivation of the entrepreneurs. Thus, a negative interaction pattern had built-up over time. As a result, the project was abandoned. Such negative interaction patterns were also found in the other biomass gasification projects. The development and implementation of biomass gasification plants involved more uncertainties than most entrepreneurs had expected. Perceived uncertainties accumulated because different sources of perceived uncertainty interacted and reinforced each other in a negative way. In addition, various internal or external factors in the project environment negatively influenced the perceived uncertainties and/or the motivation of the entrepreneurs. Due to the joint entrepreneurship of the biomass gasification projects, the withdrawal of one of the project partners (i.e. an 'internal' factor) negatively affected the motivation of the remaining entrepreneurs and frequently resulted in the termination of the project. Furthermore, the motivation of the entrepreneurs was negatively influenced by external factors like institutional change (i.e. the liberalization of the energy market, which made entrepreneurs more risk-averse) and external technological developments (i.e. the success of competing technologies reduced the motivation of entrepreneurs to invest in the development of biomass gasification). Thus, various types of negative interaction patterns were built up. Although the empirical results also showed some examples of entrepreneurs who, just like in the micro-CHP case, tried to reduce perceived uncertainties by undertaking all sorts of activities (such as lobbying, cooperating and knowledge-development activities), it was lost labour. The negative interaction patterns dominated. Since the entrepreneurs did not succeed in stopping these negative interaction patterns and their motivation no longer counterbalanced the many perceived uncertainties, most biomass gasification projects were abandoned prematurely.

Building on the insights of the biomass gasification case, the specific goal of the biomass combustion case was to gain a better understanding of the types of interaction patterns which arise between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action. The empirical results of the biomass combustion case supported the conclusion of the biomass gasification case that perceived uncertainties and motivation change over time as a result of various interactions between the factors in the project environment, the different sources of perceived uncertainty and the motivation of the entrepreneurs. In agreement with the biomass gasification case, the biomass combustion case showed that an increase of perceived uncertainty is often triggered or intensified by factors in the project environment. Important factors in these negative interaction patterns were changes in the actor constitution (e.g. the withdrawal of a technology supplier), the institutional setting (e.g. changes in the financial policy of the Dutch government) and the social environment (i.e. social acceptance of the manure combustion projects by environmental organizations). In addition, the biomass combustion case showed several examples of negative interaction patterns between different sources of uncertainty, meaning that one source of uncertainty directly or indirectly resulted in an increase of another source of uncertainty. An example that was also encountered in the biomass gasification case, was the negative influence of the uncertainties that investors perceive about biomass gasification projects (including technological uncertainty, political uncertainty and uncertainty about the availability and price of biomass resources) on the uncertainties that entrepreneurs perceive about the mobilization of financial resources. Furthermore, the analysis of the biomass combustion case demonstrated that the time-factor (i.e. the temporal duration of a project, a project-internal factor) plays an important role in the development of negative interaction patterns. In line with the findings of the biomass gasification case, the biomass combustion case showed that delay of a project increases the chance that new sources of perceived uncertainty arise or that changes in the internal or external factors negatively interact with the perceived uncertainties. Nevertheless, despite these similarities, the influence of perceived uncertainty on the continuation of entrepreneurial action differed largely between the two biomass cases. In contrast to the biomass gasification case, none of the biomass combustion projects was abandoned. Comparison of the two biomass cases provides the following explanations (see also Table 7-2).

- *technological uncertainty*

While the perceived importance of most of the uncertainty sources was very much alike, the perception of technological uncertainty differed largely between the two cases (see Section 7.2.2). In contrast to the biomass gasification case, technological uncertainty was perceived to be of minor importance in the biomass combustion case. The importance of perceived technological uncertainty affected the termination of the biomass gasification projects in two ways. First, technological uncertainty was often accompanied by other sources of uncertainty. Entrepreneurs not only perceived uncertainty about the technology, but also about the availability of biomass resources, the duration and outcome of the licensing procedure, and so on. As a result, the sum of the various perceived uncertainties easily accumulated to an unacceptable level. In the biomass combustion case, on the other hand, the sum of perceived uncertainties remained lower since perceived technological uncertainty was less important while the other uncertainty sources were equally important compared to the biomass gasification case. A second reason why technological uncertainty has contributed to the termination of the biomass gasification projects, is that technological uncertainty negatively influenced other sources of uncertainty; meaning that technological uncertainty resulted in an increase of other uncertainty sources. For instance, the existence of technological uncertainty resulted in an increase of perceived uncertainty about the reliability of technology suppliers or about the mobilization of financial resources needed for improvement of the technology. This negative interaction pattern between technological uncertainty and other sources of uncertainty contributed even more to an accumulation of perceived uncertainties in the biomass gasification projects. Thus, due to the absence of technological uncertainty, the total level of perceived uncertainties was lower and negative interaction patterns emerged less-frequently in the biomass combustion case compared to the biomass gasification case.

- *external technological developments*

Comparison of the cases also shows that the cases differ with respect to the influence of external factors. In the biomass gasification case, all of the external factors had a negative impact on the perception of uncertainties and/or the motivation of the entrepreneurs. The biomass combustion case, on the other hand, showed that external factors play an important role in the development of *negative* as well as positive interaction patterns. This is illustrated by the factor 'external technological developments'. In the biomass gasification case, the failure of other biomass gasification projects in combination with the successful developments of competing technologies (like biomass combustion) negatively influenced the motivation of the biomass gasification entrepreneurs. Since the diminished motivation of the entrepreneurs no longer outweighed the perceived uncertainties, the entrepreneurs decided to abort their activities. In the biomass combustion case, on the contrary, external technological developments had a positive influence on the motivation of the entrepreneurs. The success of biomass combustion projects abroad had such a positive influence, that even entrepreneurs of less-successful biomass combustion projects remained motivated to continue their activities despite increased levels of perceived uncertainty. Thus, external technological-developments hampered the continuation of biomass gasification projects while stimulating the continuation of biomass combustion projects. This empirical finding underlines that the external environment in which innovation projects are embedded (the Technological Innovation System, see above) has a strong impact on entrepreneurial action.

- *uncertainty management activities*

Another difference between the two cases is that the entrepreneurs of the biomass combustion projects frequently managed to reduce perceived uncertainties by undertaking various uncertainty management activities. This reduction of perceived uncertainties positively influenced the motivation of the entrepreneurs to continue their actions. In this way, positive interaction patterns between perceived uncertainties, motivation and entrepreneurial action were built up and negative interaction patterns were stopped or even prevented. However, in the biomass gasification case, most entrepreneurs were unable and/or unwilling to reduce perceived uncertainties. This seems to be related to the above-mentioned differences with respect to the perception of technological uncertainty and the influence of external factors. Due to the importance of technological uncertainty and the negative interactions between technological uncertainty and the remaining uncertainty sources, the entrepreneurs of the biomass gasification projects had to deal with many sources of perceived uncertainty simultaneously. For instance, while entrepreneurs tried to reduce technological uncertainty by investing in technology development activities, uncertainty about the mobilization of financial resources needed to finance these activities increased. Furthermore, the willingness to undertake uncertainty management activities was often lacking since the negative influence of external factors and the high level of perceived uncertainties decreased the motivation of the biomass gasification entrepreneurs to continue with their projects. Thus, the importance of technological uncertainty and the negative influence of external factors make it difficult to stop negative interaction patterns by undertaking uncertainty management activities.

- *single versus multiple entrepreneurs*

A fourth difference between the two biomass cases is the difference in the role of the entrepreneur (see Section 7.2.3). While the biomass gasification projects were all initiated by multiple entrepreneurs (technology developers together with adopters), most of the biomass combustion projects were initiated by single entrepreneurs (adopters alone). In the biomass gasification projects, the withdrawal of one of the actors involved usually resulted in the termination of the project. In the biomass combustion case, the withdrawal of actors only resulted in an increase of perceived uncertainties but never in the termination of a project. This empirical finding seems to suggest that innovation projects should preferably be undertaken by a single entrepreneur instead of multiple entrepreneurs. However, as many scholars have noted, an important incentive for firms to cooperate is to manage the high levels of uncertainty (Lambe and Spekman 1997; Hagedoorn 2002; Silipo and Weiss 2005). A big advantage of jointly fulfilling the role of entrepreneur is that perceived uncertainties can be shared and that actors can make use of the skills and resources of their partners in order to reduce perceived uncertainties. If actors have the possibility of sharing perceived uncertainties, they may be more willing to undertake entrepreneurial activities than if they would have to bear perceived uncertainties alone. Because the different types of perceived uncertainties were higher in the biomass gasification case compared to the biomass combustion case (see Section 7.2.2), it is therefore understandable that this intensive form of cooperation is mostly seen in the biomass gasification case. However, a disadvantage of shared entrepreneurship is that such intensive types of cooperation also involve additional risks (Das and Teng 2001; Koppenjan 2005). Das and Teng speak of 'relational risk', which is defined as the probability and consequences of not having satisfactory cooperation (Das and Teng 2001). In terms of the typology of perceived uncertainties introduced in this thesis, shared entrepreneurship increases the impact of perceived uncertainty about technology suppliers or consumers (depending on whose perspective is taken). The consequences of unsatisfactory cooperation with technology suppliers/consumers are larger if these actors are involved as entrepreneurs. If an entrepreneur decides to withdraw from the project, the remaining entrepreneurs not only need to find new partners for supplying the skills or products of the former partner, but also find new partners who are willing to commit money to the project and to cope with the perceived uncertainties. Thus, although joint entrepreneurship of a project has many advantages, shared entrepreneurship increases the chance that projects are aborted if one of the actors involved decides to withdraw.

- *deadlines*

The time needed to develop and implement an emerging technology is often underestimated. As long as entrepreneurs are not confronted with strict deadlines, this does not have to be a problem. However, if strict deadlines are imposed, an underestimation of the time needed usually results in the termination of the project. Comparison of the biomass gasification projects in Bladel and Hengelo with the biomass combustion project in De Lier shows that the imposition of hard deadlines with respect to the license of innovation projects is counter-productive. The entrepreneurs of these projects received a temporary license for a trial-period of three years. However, the time available to these entrepreneurs for the development and implementation of a successful-working plant was too limited in proportion to the level of perceived uncertainties. The confrontation with these strict deadlines negatively influenced the motivation of the entrepreneurs. When the validity duration of the license came to an end, the projects were abandoned. Thus, the limited validity duration of licenses forms a barrier to the continuation of entrepreneurial action. In the biomass combustion project in De Lier, the governmental authorities responsible for granting the license followed a different strategy. Instead of imposing a strict validity duration or strict emission rules, the authorities gave the entrepreneurs time to experiment with the new technology and thereby to learn how best to cope with perceived uncertainties. Because the governmental authorities closely watched the project and noticed that the entrepreneurs were trying hard to solve the technological problems, the authorities tolerated that emission rules were temporarily exceeded. Only after six years, the governmental authorities decided to put an end to the situation since all attempts to solve the technological problems had failed. But even then, the governmental authorities gave the entrepreneurs the chance to start over with a new installation. Thanks to the cooperative behaviour of the governmental authorities, the project has not been abandoned. Thus, the imposition of strict deadlines can hinder the continuation of entrepreneurial action, as the time needed to develop and implement emerging technologies is often underestimated.

- *expectations*

The motivation of both biomass gasification and biomass combustion entrepreneurs to engage in the development and implementation of these emerging technologies was based on high expectations. Biomass gasification and biomass combustion were both seen as promising technologies. However, as described in Section 7.2.3, the positive expectations about biomass combustion were based on the positive results of biomass combustion projects abroad whereas the high expectations about biomass gasification were merely based on personal beliefs and desktop studies instead of practical experience. Because the expectations about biomass gasification were not based on practical experience, they turned out to be less realistic and more 'vulnerable'

Table 7-2 Overview of key differences between biomass gasification and biomass combustion.

	Biomass gasification	Biomass combustion
Role of the entrepreneur	Fulfilled by technology developers and adopters collectively (multiple entrepreneurs)	Fulfilled by adopters (single entrepreneurs)
	Withdrawal of one of the entrepreneurs frequently resulted in project termination	Withdrawal of a project partner (e.g. technology developer) never resulted in project termination
Motivation	'Emotional'-based: driven by enthusiasm	More 'rational'-based: opting for 'proven' technology
	Expectations were based on personal beliefs and desktop studies and therefore more vulnerable	Expectations were based on results of other (foreign) projects and therefore more realistic
Perceived uncertainty	Dominant uncertainty sources: technological, political and resource uncertainty	Dominant uncertainty sources: political and resource uncertainty
	Technological uncertainty increased drastically when technological setbacks occurred	Technological uncertainty remained low despite technological setbacks
Factors in internal/ external project environment	Negative influence of external technological developments (success of competing technologies like biomass combustion decreased motivation to invest in gasification)	Positive influence of external technological developments (success of other biomass combustion projects stimulated motivation to invest in combustion)
	Projects in Bladel and Hengelo were hindered by strict deadlines due to the limited validity duration of the license	Project in De Lier was supported by tolerant policy of governmental authorities with respect to the license and the emission rules
Entrepreneurial action	Negative interaction patterns dominated. Entrepreneurs did not manage to reduce perceived uncertainties and motivation decreased.	Entrepreneurs successfully managed to reduce perceived uncertainties. Positive interaction patterns countered negative interaction patterns.

than the expectations about biomass combustion. The development and implementation of a successful-working biomass gasification plant turned out to be far more complicated than expected. As the entrepreneurs were confronted with unanticipated problems, expectations started to crumble, perceived uncertainties increased and motivation decreased. Projects were terminated because the project results fell behind of what was expected. Since the expectations about biomass combustion were based on the results of other implementation projects, these expectations were far more realistic. The advantage of this is that the technological problems which occurred were considered to be 'normal teething problems' (see Section 7.2.2). As a result, perceived technological uncertainty remained low and entrepreneurs remained motivated. Thus, it is important to carefully manage expectations with respect to emerging technologies. On the one hand, high expectations are needed to motivate entrepreneurs to initiate projects even though practical experience is still poor or lacking. On the other hand, though, high expectations easily crumble if the first practical results fall behind what is expected. The breakdown of expectations, in turn, negatively influences entrepreneurial activities. This argumentation is supported by the work of Simona Negro, who claims that the high expectations about biomass gasification initially triggered entrepreneurial activities in the Netherlands. However, as the technology failed to prove itself within the following years, expectations collapsed. According to Negro, this breakdown of expectations negatively affected the continuation of ongoing projects and the initiation of new projects. (Negro 2007)

In Table 7-2, the above differences between the biomass gasification case and the biomass combustion case are categorized according to the concepts of the analytical model.

7.2.5 Conclusions of research questions 1 and 2

The goal of this section is to provide answers to the first two research questions:

RQ1: *What are the dominant types of uncertainties as perceived by the various entrepreneurs involved in the development and implementation of micro-CHP, biofuels, biomass gasification and biomass combustion in the Netherlands?*

RQ2: *How do perceived uncertainties influence entrepreneurial action and thereby the development and implementation of these technologies?*

These research questions are answered both by within-case analysis (reported in Chapters 3 to 6) and by cross-case analysis (reported in Sections 7.2.1 to 7.2.4 of this chapter). As explained above, the biofuels case was not taken into account in the cross-case comparison. However, to answer research questions 1 and 2, in this section the outcomes of the cross-case comparison are supplemented with the outcomes of the within-case analysis of the biofuels case (see Chapter 4).

With respect to the first research question, the cross-case comparison showed that political, technological and resource uncertainty are the most important sources of perceived uncertainty with respect to the technologies studied. Political uncertainty was in all three cases (micro-CHP, biomass gasification and biomass combustion) a dominant source of perceived uncertainty. The importance of political uncertainty was mainly caused by the frequent changes to the financial instruments regarding more sustainable energy. Technological uncertainty played a dominant role in the cases of micro-CHP and biomass gasification, since practical experience with these emerging technologies was still lacking. Uncertainty about the mobilization of resources (including financial resources as well as feedstock) was dominant in the biomass gasification case and the biomass combustion case. The entrepreneurs involved in these cases perceived uncertainty about the availability, price and quality of biomass as well as about the mobilization of financial resources from external investors.

The importance of political uncertainty is confirmed by the outcomes of the biofuels case (see Chapter 4). The chronological literature review of the developments of biofuels in the Netherlands showed that political uncertainty has played a dominant role over the years. In the period 1990-1995, political uncertainty was mainly caused by a lack of clear governmental policy with respect to support for biofuels in general. In the period 1995-2002, political uncertainty shifted from uncertainty about the general support of biofuels to uncertainty about the support for first-generation biofuels. In this period, governmental policy showed a clear preference for second-generation biofuels, which resulted in great uncertainty about the level of support for first-generation biofuels. In the period 2002-2005, the Dutch government decided to abandon its preference for second-generation biofuels, as both first-generation and second-generation biofuels were needed to meet the biofuels directive of the EU demanding that the member states substitute part of their traditional transportation fuels by biofuels. As a result, uncertainty about governmental support for first-generation biofuels diminished. Nevertheless, the entrepreneurs continued to perceive uncertainty about governmental policy, since it was unclear what type of instruments (e.g. tax exemptions for biofuels or compulsory standards for substituting transportation fuels by biofuels) would be implemented to support the creation of a market for biofuels. The biofuels case furthermore showed that political uncertainty greatly influenced entrepreneurial action. Although the entrepreneurs engaged in all sorts of lobbying activities to reduce political uncertainty, this uncertainty (especially with respect to governmental support for market creation) continued to discourage firms (particularly established companies) from initiating entrepreneurial projects. Since biofuels technology is approaching market introduction, this finding is a first indication that the blocking power of perceived uncertainties on entrepreneurial action increases once a technology enters the take-off phase.

With respect to research question 2, the empirical results showed that perceived uncertainties have a great influence on the actions of (potential) entrepreneurs. The empirical data confirmed that actors are only willing to act entrepreneurially if the uncertainties they perceive are counterbalanced by a strong motivation to engage in the development and implementation of the emerging technology. Whether or not different types of actors (technology developers or adopters) were willing to fulfil the role of entrepreneur differed across the cases, as a result of differences in motivation and perceived uncertainties. The role of entrepreneur was in the micro-CHP case fulfilled by the technology developers, in the biomass gasification case by technology developers and adopters collectively, and in the biomass combustion case by the adopters. Those actors who were motivated to fulfil the role of entrepreneur tried to reduce the perceived uncertainties by initiating various sorts of activities (including lobbying, cooperation or knowledge-development activities). In the micro-CHP case and the biomass combustion case, these activities were effective in managing perceived uncertainties and, as a result, entrepreneurial action was continued. However, in the case study on biomass gasification, the technology that was in the take-off phase, the entrepreneurs did not manage to prevent perceived uncertainties from increasing over time. Whereas the motivation of the biomass gasification entrepreneurs was initially strong enough to outweigh the perceived uncertainties, most of the biomass gasification projects were abandoned prematurely. An important explanation for the termination of these projects is the frequent occurrence of negative interaction patterns between the various factors in the project environment, the different sources of perceived uncertainty and the motivation of the entrepreneurs. Perceived uncertainties accumulated, since different sources of uncertainty interacted and negatively reinforced each other. In addition, various internal factors (like the withdrawal of one of the project partners or the confrontation with strict deadlines) and external factors (like institutional change or external technological developments) negatively influenced the perceived uncertainties and/or motivation of the entrepreneurs. Because of these negative interaction patterns, perceived uncertainties increased over time while motivation decreased. Most of the entrepreneurs did not succeed in stopping these negative interaction patterns and, as a result, decided to terminate their biomass gasification activities. Since biomass gasification can only reach the acceleration phase if several entrepreneurial projects manage to become a success, the development of biomass gasification stagnated in the take-off phase.

7.2.6 Discussion of the research methodology

To justify these conclusions, it is important to reflect on the research methodology used to answer research questions 1 and 2.

A common concern about case study research is the reliability and the validity of the research approach. Reliability refers to the extent to which other researchers that follow the same procedures and conduct the same case study all over again achieve similar findings. To improve the reliability of the research, it is important to document the research procedures (Yin 2003). This was done by using a case study protocol (see Chapter 1). This protocol included, among others, a description of the case study objectives, the conceptual model, a list of interview candidates and an interview scheme. Another way to increase the reliability of the case studies is to carefully document the data collected and to use multiple data sources ('data triangulation') (Yin 2003). Since each data source has its own strengths and weaknesses, any finding or conclusion in a case study is likely to be more convincing if it is based on several different sources of information (Yin 2003). As argued in Chapter 1, interviews were the most important source of information. For each interview, an interview report was drawn up. In order to prevent biases or misinterpretations by the researcher, all interviewees were given the opportunity to review the interview report. In addition, the data from each interview was combined with data from other interviews and with information from various types of documents (including policy documents, scientific articles, project reports, professional journals and newspaper articles). To record which documents were studied, a literature database consisting of an annotated bibliography of all relevant documents was constructed.

Validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure. For exploratory research, an important type of validity is *construct validity.* Construct validity refers to the requirement that correct operational measures are established for the concepts being studied (Yin 2003). The core concept of this research was 'perceived uncertainty'. As a first step towards operationalizing this concept, a typology of perceived uncertainties was developed on the basis of an extensive literature review (see Chapter 2). Then, each type of perceived uncertainty was defined and operational measures were established. This operationalization of perceived uncertainty was tested in the first empirical case study on micro-CHP (see Intermezzo A). On the basis of this first case and the following cases, it was concluded that the typology of six sources of perceived uncertainty (technological, resource, competitive, supplier, consumer, political uncertainty) was a valuable tool for analyzing perceived uncertainties regarding the development and implementation of emerging, more sustainable energy technologies. The set of six uncertainty sources turned out to be appropriate and sufficient for the cases studied, as all perceived uncertainties which were mentioned by the interviewees could be attributed to one of the uncertainty sources. In addition, none of the uncertainty sources appeared to be irrelevant, as all sources of perceived uncertainty were found to be present in the empirical cases. Finally, construct validity is also increased by the use of multiple data sources ('data triangulation', see above) (Yin 2003).

Through this research design, the validity and reliability of the research were enhanced as much as possible. However, the question still remains to what extent the conclusions above can be generalized. This is discussed in the next section.

7.3 Towards general insights

The goal of this section is to provide an answer to the third research question of this thesis:

RQ3: *What general insights can be derived from the cases studied with respect to the influence of perceived uncertainty on entrepreneurial action in subsequent technology development phases?*

Since case study research is very time-consuming, the number of cases was restricted to only one case per phase. Due to the limited number of cases, critics of the case study approach often argue that it is difficult or even impossible to generalize the findings of case study research. A common response to this criticism, is that the goal of case study research is not to generalize to populations ('statistical generalization'), but to expand and generalize theories ('analytic generalization') (Yin 2003). "*In analytic generalization, the investigator is striving to generalize a particular set of results to some broader theory.*" (Yin 2003, p. 37) Although the opportunities for both statistical and analytic generalization increase when the number of cases is large, analytic generalization is also possible with a limited set of cases. Still, an important danger of building theory from cases is that researchers reach premature or even false conclusions as a result of information-processing biases (such as leaping to conclusions based on limited data, being overly influenced by more elite respondents or inadvertently dropping disconfirming evidence) (Eisenhardt 1989) Whereas some researchers might refrain from contributing to theory-development in order to avoid this danger, they miss the opportunity to enrich our theoretical understanding of a specific phenomenon with empirical-valid evidence. Out of the belief that still relatively little is known about the role of perceived uncertainties in the development and implementation of emerging energy technologies, in this section an attempt is made to develop some general insights from the cross-case comparison while acknowledging the limitations of this attempt.

As Eisenhardt (1989) argues, essential to good theory-building from cases is to compare the emergent findings with the existing literature. One of the main findings from the cross-case comparison (Section 7.2) was that the development and implementation of biomass gasification technology was the most problematic case. In this case, many entrepreneurial activities were abandoned as entrepreneurs did not manage to stop the negative interaction patterns and their motivation could no longer compensate for the many perceived uncertainties. An important criterion for selecting the cases was that each case focused on an emerging technology in a different phase of development. The biomass gasification case focused on the take-off phase, the phase in which the technology has just entered the market and the first adopters start buying and using the technology. The question therefore arises whether or not this finding can be attributed to the technology development phase. In order to discuss to what extent the outcomes of the cross-case comparison can be generalized, the goal of this section is to compare the empirical findings with similar and conflicting literature.

7.3.1 The take-off phase as 'Valley of Death'

The conclusion that the problems encountered in the biomass gasification case are related to the technology development phase, is supported by a broad range of innovation studies that describe that emerging technologies have to bridge a so-called 'Valley of Death', 'Innovation Gap' or 'Chasm' in order to come from the development of a 'proof of principle' to large-scale commercial application (e.g. Moore 1991; Marczewski 1997; Schepers, Schnell et al. 1999; Markham 2002; Kalil 2005; Wessner 2005; Brown 2006). In order to explain why the phase between R&D activities and large-scale commercial application (in this research called the 'take-off phase') is such a critical phase, the above-mentioned literature provides several explanations.

One of the explanations for the existence of a Valley of Death is that there is a lack of funding during this phase (Marczewski 1997; Kalil 2005; Wessner 2005). For many emerging technologies, the financing of the first phase of the technology development process (in this research called the 'pre-development phase', the phase which primarily focuses on R&D activities), is primarily based on governmental funds. These governmental funds are motivated by societal goals such as stimulating innovation in health, sustainable energy or safety. The final phase, the phase of large-scale commercialization (in this research: the second part of the acceleration phase and the entire stabilization phase), is primarily financed by private companies that are driven by profit motivations. However, funding is lacking for the critical phase in which the technology has left the laboratory but is not yet a commercial and 'proven' technology. Private parties (including banks and venture capitalists) are reluctant to invest in unproven new technologies because of the high uncertainties and the lack of a clear profit potential. In addition, governmental funding, often concentrates on R&D activities while lacking to support the subsequent activities which are needed for turning the potential of these R&D activities into useful commercial products. As a result, many promising technologies never reach the stage in which they become commercial products whose application is not only beneficial to market parties but also to society at large. This funding problem was also encountered in the empirical cases. The Dutch policy instruments which are currently in place to support emerging, more sustainable energy technologies mainly focus on the pre-development phase and the acceleration phase (Bain & Company 2006; Energy Valley 2006; Algemene Energieraad 2007). Although there are some financial instruments that aim to subsidize demonstration projects, governmental funding for the take-off phase is still modest (Bain & Company 2006; Energy Valley 2006; Algemene Energieraad 2007; Energie Forum Nederland 2007). For entrepreneurs involved in biomass gasification projects, financial support mainly stemmed from policy instruments that aimed to support the production of renewable electricity (e.g. the REB and the MEP instruments). Although these instruments formed an important incentive to invest in emerging more sustainable energy technologies, these instruments did not bring in any money until the technology had been implemented successfully and electricity was actually produced. In addition, due to the many changes to these instruments over the past years, the entrepreneurs perceived great uncertainty about this source of income. Uncertainty about the mobilization of financial resources other than governmental funding was also perceived to be high, as many private investors were reluctant to invest in 'unproven' technologies like biomass gasification. This problem was not only encountered in the biomass gasification case, but also in the biomass combustion case. Whereas entrepreneurs themselves considered biomass combustion to be a proven and commercially-viable technology, banks and other investors still perceived uncertainty about the technology and were reluctant to invest in development and implementation projects. As a result, the funding gap for emerging technologies becomes even larger. This empirical finding is supported by a recent study commissioned by the Ministry of Economic Affairs, which also concluded that there is a shortage of capital supply for sustainable energy innovation projects that are in between the R&D phase and the market introduction phase (Bain & Company 2006). The study shows that, in contrast to the general trend in Europe and North America, there is still very limited Venture Capital supply for sustainable energy innovations in the Netherlands, especially in the stages right after the R&D phase (Bain & Company 2006). International Venture Capitalists indicated that the low interest to invest in sustainable energy in the Netherlands relative to other European countries first of all stems from the lack of a clear and stable long term vision and policy of the Dutch government (Bain & Company 2006). Thus, the uncertainty that Dutch entrepreneurs perceive about the mobilization of financial resources for the development and implementation of emerging energy technologies is, both directly and indirectly, negatively influenced by political uncertainty.

According to the innovation literature, the phase between R&D and large-scale market diffusion is not only hampered by a funding problem, but also by a marketing problem. Building on the adoption and diffusion theory of Everett Rogers (Rogers 1995), scholars like Geoffrey Moore argue that there is a 'Chasm' between the market for the 'early adopters' of the technological product (the 'visionaries') and the 'early majority' (the 'pragmatists') (Moore 1991). Both of these groups have very different expectations from the technology. Visionaries are driven by a dream. They believe in the business opportunities which the adoption of the emerging technology has to offer and are willing to take high risks in achieving their goal. While visionaries might accept that the technology does not yet function optimally, pragmatists, on the other hand, are not willing to buy a technological product unless the quality of the product as well as the reliability of the supplier from whom they are buying the product are proven. In deciding whether or not the product and the supplier satisfy these conditions, pragmatists do not look at visionaries for good references, but look for good references from other pragmatists. Thus, the problem is how to convince the first pragmatists to adopt technologies that are not yet proven. As a result of this marketing problem, many emerging technologies never reach the mainstream market. The difference between visionaries and pragmatists was also encountered in the cross-case comparison (see Section 7.2.3). In the biomass gasification projects, the entrepreneurs were strongly driven by enthusiasm about biomass gasification technology and can therefore be classified as 'visionaries'. Since biomass gasification has not yet established sufficient good references (not even among the visionaries), it is still too early to convince the first pragmatists to invest in the technology. In the biomass combustion case, good references were provided by successful biomass combustion projects abroad. Although some biomass combustion entrepreneurs were 'visionaries' who acted out of enthusiasm and accepted high levels of uncertainty, most entrepreneurs of the biomass combustion case can best be categorized as 'pragmatists'. These pragmatists were unwilling to invest in 'unproven' technology and based their decision to invest in biomass combustion on the good references from abroad. What is interesting, though, is that the entrepreneurs involved in the two biomass cases were to a large extent identical. Organizations which fulfilled the role of 'visionary' in the biomass gasification case acted as 'pragmatists' in the biomass combustion case. The strategy to act as a visionary in one project and as a pragmatist in another project is rational, considering the high levels of uncertainty which are encountered when acting as a visionary. However, the cases also showed that some organizations which acted as a visionary in an unsuccessful biomass gasification project became reluctant to again act as a visionary.

When they considered investing in another bio-energy project, they specifically opted for 'proven' technology with low levels of uncertainty. If too many organizations within the energy sector switch from being visionary to being pragmatist, it can become problematic for emerging 'unproven' technologies to break through.

Still another explanation for the high failure rate of emerging technologies in this phase is found at the firm level (Schepers, Schnell et al. 1999; Markham 2002). In order for firms to turn technological inventions into commercial products, firms must possess the skills and resources to perform both R&D activities and commercialization activities (Markham 2002). However, SMEs (small and medium-sized enterprises) may be lacking some of these skills and resources. It is often argued that small firms have more difficulty than large firms to acquire the financial resources and the skilled technical personnel needed to invest in R&D. Moreover, small firms often lack the marketing skills as well as the access to distribution and marketing channels which are needed to commercialize innovations (Nooteboom 1994; Freel 2000; Roijakkers 2003). Large companies, on the other hand, often encounter difficulties in translating successful research into commercial products because of the large distance between R&D departments and marketing departments. Technical personnel and marketing personnel find it difficult to cooperate, since both groups have different objectives and reward structures and often do not understand the concerns of the other group (Markham 2002). Technical people find value in discovering and improving the technology, while marketing people need a product to sell and often consider the value of a discovery as theoretical and useless (Markham 2002). One of the risks of poor cooperation is that technical personnel only has eye for the technology and therefore keeps the product in the laboratory for too long, with the consequence of loosing the potential market to competitors or inventing a product which adopters do not want. Another risk is that marketing personnel wants to launch the product on the market too soon, with the consequence that the technology does not function properly and adopters (especially the 'pragmatists' as defined above) are scared away. Because of these problems with combining good R&D skills with good marketing skills, many promising technological inventions do not succeed in bridging the gap between the laboratory and the marketplace. In the biomass gasification case, the technology also entered the market when the technology did not yet function properly. The technological problems encountered with the first operational plant (the Amer-project, see Chapter 5) were heavily underestimated. As a result, these problems greatly affected the perceived uncertainties and the expectations about biomass gasification technology. Not only the entrepreneur of the Amer-project, but people in the whole sector started to realize that expectations had been overly optimistic and uncertainties heavily underestimated. Consequently, many entrepreneurs and banks became reluctant to invest in biomass gasification projects. What makes it even more difficult for the kind of emerging technologies that were studied in this research, is that emerging energy technologies enter the market as 'first-of-a-kind' products which still need to be adapted to the specific circumstances at the location of application (such as the available feedstock). Hence, the problem with these kinds of technologies goes further than the above described problem of technology developers who need both R&D skills and marketing skills. In order for these technologies to be successful on the marketplace, both knowledge of the technology developer and knowledge of the adopter are needed. Therefore, good cooperation between technology developers and adopters is essential for making the first technologies successful on the market. Moreover, due to the specific requirements at the location of application, the problem with these technologies is that successful implementation of one energy plant does not give any guarantees about the success of subsequent energy plants. This makes it even more difficult for these technologies to grow from 'visionary' markets to 'pragmatist' markets.

Thus, the above-mentioned studies provide several arguments which explain why the take-off phase (the phase between R&D and large-scale commercial application) is the most critical phase in the development of emerging technologies. Since the problems outlined in these studies are in line with the empirical results, it seems reasonable to assume that the high failure rate of entrepreneurial projects in the biomass gasification case is related to the technology development phase (i.e. biomass gasification is in the take-off phase). The added value of this research to the above literature is that more insight is given into the underlying dynamics which explain why so many entrepreneurial projects fail in this critical phase. The typology of perceived uncertainty sources has proven to be a useful tool for identifying and analyzing a wide variety of problems which entrepreneurs face (i.e. uncertainty about governmental policy, the mobilization of financial resources, the reliability of suppliers, the development of a market, and so on). Moreover, by focusing on interaction patterns, this research has shown that these problems are not independent but negatively reinforce each other. The empirical results of this research have shown that the high failure rate of entrepreneurial projects during the take-off phase can be explained by the many negative interaction patterns between different sources of perceived uncertainty, various factors in the project environment and the motivation of the entrepreneurs, leading to an accumulation of perceived uncertainties and a decreasing motivation to act entrepreneurially. Furthermore, whereas most innovation studies focus either on the perspective of the technology developers or on the perspective of the adopters (buyers and users of the technology), an additional merit of this research is that it combines the perspective of technology developers with the perspective of adopters. Including these different types of actors in the analysis is important, since emerging energy technologies require the involvement of both technology developers and adopters to survive the take-off phase.

7.3.2 Technological complexity

Whereas the above-mentioned literature supports the argumentation that the differences between the cases are influenced by technology development phases, it is important to examine other plausible explanations as well. An important alternative explanation would be to attribute the differences between the cases to the technological characteristics. Innovation scholars have argued that radical, complex technological innovations (like biomass gasification) involve a higher degree of technological uncertainty than more incremental innovations (like biomass combustion) (e.g. Rogers 1995; Shenhar, Dvir et al. 1995). In other words, one might argue that the termination of the biomass gasification projects was the result of the high technological complexity, whereas the success of the biomass combustion projects stemmed from the low technological complexity. However, the finding that so many biomass gasification projects were abandoned does not necessarily imply that the implementation of this technology was just not technologically feasible. The biomass gasification project at the Amercentrale (see Chapter 5) illustrates that even the development and implementation of such a complex technology can be successful, provided that the entrepreneur has a strong motivation, a substantial period of time (here: seven years) and enough resources available to experiment with the technology and learning how best to manage perceived uncertainties. In addition, looking at the biomass combustion case, it becomes clear that not all biomass combustion projects progressed smoothly. Especially the first biomass combustion projects (the first wood combustion projects in De Lier and Schijndel and the first manure combustion projects in Moerdijk and Apeldoorn) show some resemblance to the biomass gasification projects, as perceived uncertainties were underestimated and proved difficult to manage. Comparing these first projects with the more recent wood combustion projects, it appears that biomass combustion technology gradually developed into a reliable technology with low uncertainties. Thus, the differences between the biomass gasification case and the biomass combustion case cannot be attributed to the technological characteristics alone. However, the argument that the technological characteristics influence the degree of perceived uncertainty not so much contradicts the argument of the importance of the technology development phases, but rather complements it. As Tushman and Rosenkopf argue, the level of (technological) uncertainty is dependent on the technology development phase, as well as on the complexity of the technology (Tushman and Rosenkopf 1992). To phrase it differently: the high importance of perceived technological uncertainty in the biomass gasification case compared to the biomass combustion case was the result of both the earlier technology development phase and the higher complexity of the technology. Since radical technologies involve more uncertainties, they will need more time, money and effort to survive the take-off phase than incremental technologies. In the biomass gasification case, the time and resources available to experiment with the technology were insufficient to reduce the high level of perceived uncertainties which were encountered during the take-off phase. Therefore, sufficient time, effort and resources should be made available in order to increase the chance that emerging, more sustainable energy technologies (especially radical technologies) survive the take-off phase.

7.3.3 Conclusions of research question 3

The goal of this section was to provide an answer to the third research question:

RQ3: *What general insights can be derived from the studied technologies with respect to the influence of perceived uncertainty on entrepreneurial action in subsequent technology development phases?*

One of the main conclusions from the cross-case comparison is that the case on biomass gasification, the technology which was in the take-off phase, was the most problematic case. The goal of this section is to discuss whether these findings can be attributed to the technology development phase. Due to the limited number of cases and the information-processing biases of people, it remains difficult for a case study researcher to argue that the study's findings are generalizable beyond the immediate cases studied. To strengthen the grounds for generalization as much as possible, the case study findings were compared to similar and conflicting arguments put forward in the innovation literature.

The conclusion that the problems encountered in the biomass gasification case are related to the technology development phase is supported by a broad range of innovation studies, which describe the phase between R&D activities and large-scale commercial application (in this research called the 'take-off phase') as a 'Valley of Death', and 'Innovation Gap' or a 'Chasm'. This body of literature provides several explanations for the high failure rate of emerging technologies during this critical phase. According to this literature, many promising technologies never bridge the phase between R&D and large-scale commercialization because of a lack of funding, the existence of a gap between the market for the 'early adopters' (the 'visionaries') and the 'early majority' (the 'pragmatists'), and the organizational problems of combining good R&D skills with good marketing skills. Since the empirical results of this research are in line with this body of literature, it seems reasonable to assume that the high failure rate of entrepreneurial projects in the biomass gasification case is related to the technology development phase. The added value of this research to the above-mentioned literature is that it provides further insight into the underlying dynamics that cause so many entrepreneurial projects to fail in this critical phase. This research has shown that the problems mentioned in the literature above are not independent, but negatively reinforce each other. The many negative interaction patterns found in the empirical data help to better understand why so many entrepreneurs decide to abandon their activities during the take-off phase.

A rival explanation for the outcomes of the cross-case comparison is that the differences between the cases studied are related to the technological characteristics. Innovation scholars have argued that radical, complex technologies (like biomass gasification) involve a higher degree of technological uncertainty than more incremental technologies (like biomass combustion). Therefore, one might argue that the termination of the biomass gasification projects was due to the high technological complexity, whereas the success of the biomass combustion projects stemmed from the low technological complexity. However, when taking a closer look at these cases, it becomes clear that not all biomass gasification projects failed and not all biomass combustion projects were a success. Even radical technologies like biomass gasification can be successfully implemented, provided that the entrepreneur has a strong motivation, a substantial period of time and sufficient resources available to manage the high level of uncertainties. And even the implementation of incremental technologies like biomass combustion can involve great uncertainty if the technology has not yet fully established itself as a proven technology and the entrepreneurs still have to learn how best to deal with the perceived uncertainties. Thus, the technological characteristics alone cannot fully explain the empirical findings. To put it differently, the differences in technological characteristics between the cases not so much reject the influence of the technology development phase on the outcomes of the cross-case comparison, but rather provide a complementary explanation for the empirical findings. Since radical technologies involve more uncertainties, they will need more time, money and effort to survive the take-off phase than incremental technologies. In the biomass gasification case, the time and resources available to experiment with the technology were insufficient to reduce the high level of perceived uncertainties and the many negative interaction patterns encountered during the take-off phase.

Having compared the empirical findings with rival and complementary explanations, there seems to be sufficient ground to expect that the high level of perceived uncertainties and the many negative interaction patterns found in the biomass gasification case will also be found in other cases concerning emerging, more sustainable energy technologies in the take-off phase. The final chapter discusses what the implications of these findings are for policy-makers and managers who aim to stimulate the development and implementation of emerging, more sustainable energy innovations.

Notes

1 In the literature, different types of Innovation Systems are discerned (e.g. National, Regional, Sectoral and Technological Innovation System). Since the interest of this thesis lies in the development and implementation of emerging technologies, a Technological Innovation System approach is used. This approach is most suitable, since it focuses on a particular technology and includes factors that are specific to the technology studied. (Carlsson and Stanckiewicz 1991; Jacobsson and Johnson 2000; Negro 2007)

2 Obviously, entrepreneurs can undertake more activities than only performing experimental projects. Entrepreneurs also play an important role in the fulfillment of other key activities in the development and implementation of new technologies, like knowledge development, creation of legitimacy, etc.

3 This is in line with the biofuels case, in which entrepreneurs also reacted to perceived political uncertainty by undertaking lobbying activities. See Chapter 4.

4 The license was only valid for a trial-period of three years.

8

Implications for policy and management

8.1 Introduction

Building on the insights from the previous chapter, the goal of this final chapter is to answer the last research question as formulated in Chapter 1:

RQ4: *What are the implications for policy and management?*

The chapter consists of three sections. The chapter starts with a discussion of the ambiguous nature of uncertainty as both a stimulus and a barrier to innovation and entrepreneurial action (Section 8.2). Due to this ambiguous relation between uncertainty and innovation, policy-makers cannot and should not strive to completely eliminate the uncertainties that entrepreneurs perceive. However, as Section 8.3 describes, the empirical findings of this research have put forward several important reasons to adapt the Dutch policy currently in place to better support entrepreneurial action in the development and implementation of emerging, more sustainable energy technologies. Therefore, in Section 8.4, suggestions are put forward to improve energy innovation policy.

8.2 The ambiguous relationship between uncertainty and innovation

The empirical results of this research have shown that perceived uncertainty often acts as a barrier for entrepreneurs who are engaged in the development and implementation of emerging, more sustainable energy technologies. However, this does not mean that uncertainty is something 'negative' that should be avoided at all costs. First of all, due to the inherently uncertain character of innovation (Nelson and Winter 1977; Dosi 1982; Edquist 1997; Smits and Kuhlmann 2004), avoiding uncertainty is simply impossible when engaging in innovation activities. Second, uncertainty not only hampers but also stimulates innovation and entrepreneurship. Scholars have argued that firms operating in an uncertain business environment tend to assume more risks and be more proactive and innovative than firms in stable environments (Jauch and Kraft 1986). Clark, for instance, even argues that substantial technological and market uncertainty are important preconditions for innovation, as these uncertainties trigger a search and learning process which drives innovation and change (Clark 1985). In the entrepreneurship literature, uncertainty is seen as providing opportunities for entrepreneurs to make profit by engaging in innovation activities (Van Gelderen, Frese et al. 2000; Freel 2005). Thus, uncertainty is related to innovation and entrepreneurial action in an ambiguous way (Van Gelderen, Frese et al. 2000). On an abstract level, uncertainty is a precondition for innovation and entrepreneurship to occur. However, on a more concrete level (e.g. entrepreneurial decision-making concerning concrete innovation activities or projects), uncertainty becomes a barrier for entrepreneurs as it signifies a lack of control over the outcomes of their actions. The reason why this research has mainly shown the negative influence of uncertainty on entrepreneurial action is that the empirical cases focused on the level of concrete innovation activities. This ambiguous relationship between uncertainty and innovation confronts policy-makers with a dilemma. Acknowledging that uncertainty is an inevitable characteristic and probably even a 'sine qua non' of innovation, one realizes that policy-makers cannot and should not strive to completely eliminate the uncertainties that entrepreneurs perceive. On the other hand, the empirical cases of this research demonstrate that the current situation in which uncertainties hinder entrepreneurial action is not beneficial to innovation either. In the following section, several important shortcomings of the current Dutch energy innovation policy are discussed in more detail.

8.3 Reasons for change

The empirical results revealed two important problems that deserve more attention by policy-makers. First, all of the empirical cases (micro-CHP, biofuels, biomass gasification and biomass combustion) show that political uncertainty is one of the most dominant sources of perceived uncertainty hindering the development and implementation of emerging, more sustainable energy technologies in the Netherlands. Since the development and implementation of emerging energy technologies require large investments with payback periods of at least ten years, a stable and predictable investment climate is needed. However, the frequent and often unexpected changes in the financial policy for sustainable energy over the past years undermine this investment climate. Although the Dutch government, quite understandably, can never promise full stability in terms of specific policy instruments (i.e. policy instruments may need to be adapted in response to election results or the opportunistic behaviour of entrepreneurs), it is also understandable that the extent to which the sustainable energy policy has shifted over the past decades has provoked considerable uncertainty among entrepreneurs and other investors (banks, venture capitalists, etc.). As was concluded from the empirical findings as well as from several policy evaluation studies (Bain & Company 2006; Algemene Energieraad 2007), this political uncertainty is hindering investments in more sustainable energy technologies in the Netherlands. This poses a crucial dilemma: while certainty is indispensable, the government cannot be expected to simply provide this certainty. The question of how to deal with this dilemma is addressed in the next section on policy recommendations.

Second, the empirical results indicate that the influence of perceived uncertainty on entrepreneurial action is most severe in the take-off phase (i.e. the phase in-between R&D and large-scale market diffusion, also called the "Valley of Death"). As the biomass gasification case has demonstrated, many entrepreneurial projects are abandoned in this phase because the perceived uncertainties are high and difficult to manage. An important reason for this is that various sources of perceived uncertainty (particularly political uncertainty, technological uncertainty, and uncertainty about the mobilization of feedstock and financial resources) interact and negatively reinforce each other. In order to prevent so many entrepreneurial projects from being abandoned, governmental policy should especially be aimed at supporting entrepreneurial action in this critical phase. However, as was argued in Section 7.3.1, the policy instruments currently in place to support more sustainable energy technologies mainly focus on the phases before and after the take-off phase (Bain & Company 2006; Energy Valley 2006; Algemene Energieraad 2007). For example, the pre-development phase is supported through various R&D-grants (including EOS[1] and WBSO[2]). The acceleration phase is supported by financial instruments such as the MEP[3] (a subsidy for the production of electricity using renewable energy sources or CHP-installations) and various tax deduction instruments for investments in renewable energy and energy-savings technologies (namely, EIA, MIA and VAMIL[4]). Although there are some instruments, such as UKR[5] and DEMO[6], that aim to subsidize demonstration projects, financial support for the take-off phase is still modest (Bain & Company 2006; Energy Valley 2006;

Algemene Energieraad 2007; Energie Forum Nederland 2007). Even though entrepreneurs who invest in technologies that are still in the take-off phase can also apply for a MEP-subsidy, this subsidy does not bring in any money until the technology has been implemented successfully and electricity is actually produced. Furthermore, the MEP-subsidy is a *generic* instrument, which does not make a distinction between innovative technologies and incumbent technologies (Sociaal-Economische Raad 2006; Energie Forum Nederland 2007). Since investments in innovative 'unproven' technologies are usually more expensive and involve more uncertainties than investments in incumbent 'proven' technologies, these types of *generic* instruments provide insufficient incentive to invest in technologies that are still in the take-off phase. Thus, additional financial support for the take-off phase is required. Moreover, the empirical findings indicate that the problems encountered in the take-off phase are not exclusively related to uncertainty regarding the mobilization of financial resources. The accumulation of various sources of perceived uncertainty and the decreasing motivation of entrepreneurs, which together led to the termination of entrepreneurial projects, were often negatively reinforced by various factors in the project environment. Factors like the imposition of strict emission rules or the limited validity duration of a project's license contributed to the decision of entrepreneurs to abandon their projects. Therefore, it can be concluded that financial instruments alone are insufficient to prevent so many entrepreneurial projects from failing in the take-off phase. Hence, also non-financial measures (such as adjustments to the emission regulation and the licensing procedure) are needed to support entrepreneurial action during this critical phase.

The Dutch government is becoming increasingly aware of the above-mentioned problems. Under the framework of the 'energy transition policy', the government is developing a new policy approach aimed at stimulating specific technological paths towards a more sustainable energy system. This policy approach combines generic instruments with technology-specific support. This is done by establishing platforms consisting of representatives from market participants, scientific institutes, non-governmental organizations and governmental authorities, who together try to stimulate specific technological paths. In this new approach, non-financial instruments are applied as well. A good example is the newly established 'Koplopersloket' (that is, the 'Frontrunners Desk'). Entrepreneurs involved in sustainable innovation projects can contact this desk for support on various issues, ranging from a lack of financing to barriers posed by existing regulations. This policy instrument serves two goals: supporting these specific projects and learning what type of policy support is needed to stimulate entrepreneurial action.

Although this new policy approach is very promising, it is still in its infancy. Recent policy evaluation studies argue that the current policy is still too fragmented (Sociaal-Economische Raad 2006; Taskforce Energietransitie 2006; Energie Forum Nederland 2007). The current policy portfolio consists of instruments that only focus on one phase of the innovation process instead of taking the whole innovation process from R&D to large-scale market diffusion into account. In addition, the different instruments supporting more sustainable energy innovations are scattered across various ministerial departments. As a result, the different policy instruments are insufficiently connected so that the successful completion of one phase does not automatically lead to success in the following phase. To address these problems, the policy evaluation studies suggest reorganizing the policy portfolio in such a way that more sustainable energy technologies are supported through all the successive phases of the innovation process (Sociaal-Economische Raad 2006; Taskforce Energietransitie 2006; Energie Forum Nederland 2007). As illustrated by the following quote of the Energy Transition Taskforce (an important advisory body in the energy transition policy framework), the findings of this research project can contribute to the elaboration of these plans. In its proposal to reorganize the Dutch energy innovation policy, the Energy Transition Taskforce argues that: "*The relationship between financial and non-financial means can be properly established only when the entire transition path and the risk profile in the various phases of the path are taken into consideration.*" (Taskforce Energietransitie 2006, p. 13) Building on the research findings regarding the various sources of perceived uncertainty that are influencing the decisions of entrepreneurs in different phases of the innovation process, the final section reflects on the design of such an improved policy strategy.

8.4 An outlook on energy innovation policy

The previous section showed that the policy instruments currently in place to support emerging, more sustainable energy technologies are of short duration, do not provide sufficient support in the take-off phase and are too fragmented. In order to counteract these problems, government policy should aim to support these technologies through all the successive phases of the innovation process. Before discussing what measures are needed in each of the phases, two basic conditions for this type of policy are discussed.

8.4.1 The basic conditions

Supporting technologies through the entire innovation process requires long-term commitment. To ensure that this type of long-term governmental support becomes successful, two important conditions have to be met. First, governmental support should concentrate on a restricted number of technologies. Since governmental resources are limited, it is important to choose special areas of focus. Without some form of selection, there will be insufficient resources left over to support individual technologies through all the successive phases of the innovation process. By focusing on a limited number of promising technologies, governmental resources can be allocated more efficiently and effectively.

Second, governmental support for a specific technology should not be unconditional. As argued in Section 8.2, uncertainty is both a barrier to and an incentive for innovation. In Section 8.3, it was argued that the uncertainty that entrepreneurs currently perceive about long-term governmental policy is hindering the development and implementation of emerging, more sustainable energy technologies. By reorganizing the policy portfolio in such a way that entrepreneurs and investors feel more certain of receiving long-term governmental support, this barrier can be removed. However, reducing uncertainty about long-term governmental policy may have the unintended side-effect of removing the incentives for innovation. Establishing progress criteria is a powerful instrument to avoid this unintended side-effect. The threat of losing governmental support if these criteria are not met will motivate entrepreneurs to keep investing in the learning process needed to come up with the best possible solution. Therefore, governmental support should only be continued if substantial progress is made.

To meet these conditions, the policy design must include arrangements for the selection and evaluation of technologies. However, a danger of linking governmental support to technology evaluations is that the government can be accused of 'picking winners' or 'supporting pet technologies'. Since the government does not dispose over the required information to assess which technology will eventually be the most promising, the government should abstain from performing technology evaluations itself. Following the example of independent credit rating or technology rating institutes, one of the ways to organize such technology evaluations is to outsource them to an independent committee or institute composed of experts that are able to evaluate the competing technologies on their technological, commercial, environmental and societal aspects. On the basis of an extensive evaluation, such an independent committee rates the risk/reward potential of the technology and gives an advice to the government. This advice should weigh heavily in the decision-making process of the government regarding which technologies to support. Those technologies that are selected should receive governmental support until interim evaluations demonstrate that the progress criteria are no longer met or until the emerging technology has become an established technology that no longer needs governmental support.

8.4.2 Accelerating the phases

To support the selected technologies throughout the entire innovation process, specific measures should be taken in each phase. Based on the empirical results, the following suggestions are made.

The pre-development phase

The empirical results of the micro-CHP case and the biofuels case have shown that uncertainty about the type of policy support that the new technology will receive is an important source of uncertainty in the pre-development phase. The pre-development phase is the R&D phase in which prototypes are developed. The phase ends when the technology is introduced onto the market. The empirical cases have demonstrated that when technologies are approaching the end of the pre-development phase, uncertainty about governmental support for the creation of a market becomes very important. Although the first-generation of biofuel technologies and micro-CHP systems were expected to enter the market soon, the empirical results showed that it was still unclear if the government would stimulate the creation of a market for these technologies and, if so, what types of instruments would be applied (e.g. favourable tax regimes, a guaranteed market share of biofuels or a guaranteed electricity feed-in price for micro-CHP systems). The biofuels case in particular showed that this political uncertainty deterred entrepreneurs from initiating entrepreneurial projects and thereby launching the technology onto the market. In other words, uncertainty about governmental support for the creation of a market hampered these technologies from entering the next phase.

To avoid slowing down the development of promising emerging energy technologies, the government should not wait until these technologies enter the market but should aim instead to inform actors on time about the policy measures that will be taken to stimulate market creation for these technologies. However, policy-makers are not inclined to act early because of the uncertainties they themselves perceive about the techno-economic potential and the societal benefits of the new technology and about the strategies of the entrepreneurs involved. As the biofuels case illustrated, this situation can lead to stagnation: while entrepreneurs wait for certainty about governmental policy, the policy-makers wait for certainty about the outcomes of entrepreneurial action.

A strategy that can help manage uncertainties and prevent early stagnation in this phase is to enhance interaction between policy-makers, entrepreneurs and other stakeholders involved in the development and implementation of the emerging technology (De Bruijn, Ten Heuvelhof et al. 2002; Koppenjan and Klijn 2004; Van Merkerk 2007). To initiate and facilitate this interaction process, it is useful to have a first overview of the field. Such an overview should answer questions like: what are the recent technological developments, which actors are involved, what are potential opportunities and barriers for cooperation, what type of information seems to be lacking in order for the various actors to decide on a course of action, and so on. An independent committee of experts, as described in Section 8.4.1, could take on the task of developing such an overview. This overview can then serve as important input for an interaction and negotiation process between the various stakeholders. Using this overview as a starting point, the different stakeholders have the opportunity to learn about the viewpoints and strategies of the other actors involved and develop and discuss different scenarios with respect to the further development of the new technology. In this way, they can arrive at agreements on the conditions that have to be met to accomplish that each actor plays his part in the innovation process. With respect to the above-mentioned uncertainties, this would imply that entrepreneurs articulate what type of governmental support is needed for them to initiate projects, and that policy-makers articulate the conditions that need to be met to receive governmental support. Furthermore, other stakeholders like private investors or potential users can articulate under which conditions they are willing to become actively involved in the development of the emerging technology. Hence, early interaction between the different stakeholders may help to create a basis for joint action and thereby to accelerate the technology development process.

The take-off phase

The take-off phase is the phase in which the technology has just entered the market and the first adopters start buying and using the new technology. As argued in the previous chapter (Section 7.3), this is the most critical phase in the development and implementation of emerging technologies. The biomass gasification case showed that many entrepreneurial projects are abandoned in this phase because perceived uncertainties are high and difficult to manage due to the negative interaction patterns that build up over time.

For an emerging technology to survive this difficult phase, it is essential that the technology gains critical mass. This can only be achieved if a sufficiently large number of entrepreneurial projects aimed to develop and implement the new technology manage to succeed. One way for government to help promising technologies through this critical phase is to support a limited group of entrepreneurs in their attempts to successfully develop and implement the emerging technology. In other words, governmental support for a limited selection of promising technologies should in this phase be complemented with support for a limited number of pioneer projects. By supporting a limited number of pioneer projects, a niche market can be established in which sufficient room is provided to experiment with the new technology and to learn how best to deal with the various sources of perceived uncertainty that are encountered. If these pioneer projects manage to become successful, this will encourage other entrepreneurs to initiate projects. Thus, supporting a limited group of pioneer projects can help speed up the development of new technology.

To support these pioneer projects, governmental policy should aim to help the entrepreneurs of these projects to put an end to the build-up of negative interaction patterns. Since the empirical results showed that the types of negative interaction patterns which emerge in this phase are to a large extent project-specific, governmental support should be aligned with the specific problems encountered in the pioneer projects.[7] To illustrate, the negative interaction pattern encountered in the biomass gasification project in Hengelo (see Figure 7-3) might have benefited from a tailor-made portfolio of instruments aimed at:

- reducing technological uncertainties, for instance by facilitating knowledge-exchange between and among entrepreneurs (including foreign entrepreneurs), research institutes, universities and technical consultancy firms
- reducing uncertainty about the mobilization of financial resources, for instance by creating favourable conditions for private investors or by establishing a Participation Fund in which government and private investors jointly invest in pioneer projects
- avoiding that the license of the project includes emission rules or deadlines that are too strict, for instance by granting a special, more-flexible license to a limited number of pioneer projects.

To decide which projects deserve to be considered for this tailor-made support, the projects should be rated on the basis of their technological, environmental and commercial potential as well as on the management skills of the entrepreneurs involved. As argued in Section 8.4.1, this task should not be performed by the government, but is better delegated to an independent committee. Another important task that such an independent committee could perform is to analyze the dominant sources of perceived uncertainty and the critical factors that are causing negative interaction patterns to emerge, and to identify possible solutions to stop these negative interaction patterns. With respect to technological uncertainty, this may include the identification of specific knowledge gaps and opportunities for knowledge-exchange. With respect to uncertainty about financial resources, it may be helpful to examine under which conditions private investors would be willing to invest in pioneer projects.

The outcomes of these project ratings and problem identifications can serve as important input for policy-makers in deciding which projects to support and what strategies to apply to improve the success rate of these projects. Aside from policy-makers, banks and other private investors can also benefit from independent project evaluations. As argued in the previous chapter (Section 7.3.1), investors are reluctant to invest in Dutch energy innovation projects due to the high level of perceived uncertainties surrounding these projects. Establishing an independent project rating process may serve as an important tool for investors to obtain better insight into the risk/reward potential of energy innovation projects and thereby to reduce perceived uncertainties. Looking at the success of credit rating systems, a positive project evaluation by an independent rating committee may very well convince investors to commit money to the project. Since the empirical results showed that uncertainty about the mobilization of financial resources was one of the most dominant sources of uncertainty in the take-off phase, greater investments in these projects may significantly improve the success rate of entrepreneurial action in this phase.

The acceleration phase

The acceleration phase is the phase in which the new technology starts to diffuse rapidly. The biomass combustion case showed that governmental support remains important even for technologies that have managed to reach this phase. Although uncertainties are smaller and easier to manage than in the preceding phase, some sources of uncertainty remain to form a barrier to entrepreneurial action. Aside from uncertainty about the stability of the governmental policy, entrepreneurial action in the biomass combustion case was hindered by uncertainty about the mobilization of resources. In the Netherlands, there is still insufficient risk capital to invest in more sustainable energy technologies. This not only holds for technologies that are not yet 'proven' (like biomass gasification), but also for technologies such as biomass combustion of which successful reference projects are already available.

Therefore, the policy strategies mentioned above to mobilize additional funding (e.g. creating favourable conditions for private investors, establishing a Participation Fund) can also help stimulate entrepreneurial action in the acceleration phase. However, governmental support should not continue forever. Once the new technology has acquired a sufficiently large market share, it will become much easier for entrepreneurs to further mobilize financial resources from private investors. The share of governmental funding in entrepreneurial projects can therefore be gradually decreased. Interim progress evaluations of the independent committee can help to determine when the government can withdraw.

To conclude

Since uncertainty is a key component of innovation, it is important to develop theories that enhance our understanding of the sources and impact of uncertainty on innovation activities. This research has aimed to contribute to the development of these necessary conceptual insights. Within the domain of emerging, more sustainable energy technologies, this research has identified the main sources of uncertainty and the influence of these uncertainties on the actions of the various entrepreneurs involved. However, still a lot of work remains to be done. To further elaborate and validate the conceptual insights of this research, both empirical and theoretical research should be continued. Another important issue that deserves more attention is the issue of how to design and implement appropriate policy strategies for better dealing with uncertainty. As this final chapter has shown, this is an extremely complicated issue. Hopefully, the ideas that have been suggested here will inspire researchers, policy-makers and entrepreneurs to continue the work in this area.

Notes

1 EOS = Energie Onderzoek Subsidie (Energy Research Subsidy), including NEO (New Energy Research), LT (Long Term) and ES (Energy and Collaborative Projects).
2 WBSO = Wet Bevordering Speur en Ontwikkelingswerk (a tax credit for R&D)
3 MEP = Milieukwaliteit Elektriciteitsproductie (Environmental quality of Electricity Production)
4 EIA = Energie-investeringsaftrek (Energy Investment Deduction), MIA = Milieu-investeringsaftrek (Environmental Investment Deduction), VAMIL = Willekeurige Afschrijving Milieu-investeringen (Arbitrary Depreciation of Environmental Investments)
5 UKR = Unieke Kansen Regeling (Unique Opportunities Scheme)
6 DEMO (also part of EOS) is a scheme aimed at subsidizing demonstration projects.
7 This idea of tailor-made support for pioneer projects links up well with the newly established 'Kopplopersloket' (Frontrunners Desk; see Section 8.3).

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Appendix A Overview of interviewees and visits to bio-energy plants

Table A-1 Overview of interviewees.

	Name	Organization	Case
1	Mrs M. Van Gastel	Cogen Projects	micro-CHP
2	Mr J. Noordhoek	Delta	micro-CHP
3	Mr L. Bekkering	Enatec	micro-CHP
4	Mr P. Lely	Essent	micro-CHP
5	Mr H. Overdiep	Gasunie	micro-CHP
6	Mr M. Colijn	Microgen	micro-CHP
7	Mr M. Van Groeningen	Nuon	micro-CHP
8	Mrs J. Ter Hennepe	Vaillant	micro-CHP
9	Mr P. Dielissen	Wonen Breburg	micro-CHP
10	Mr P. Aubert	Ministry of Economic Affairs	micro-CHP + general
11	Mr A. Schoof	Ministry of Economic Affairs	biomass gasification + general
12	Mr K. Kwant	SenterNovem	biomass gasification + general
13	Mr H. Knoef	BTG	biomass gasification
14	Mr W. Duis	Duis V.O.F.	biomass gasification
15	Mr B. Van der Drift	ECN	biomass gasification
16	Mr W. Willeboer	Essent	biomass gasification
17	Mr C. Daey Ouwens	formerly a.o. Province of North-Holland	biomass gasification
18	Mr G. De Boer	formerly Province of North-Holland	biomass gasification
19	Mr E. De Kant	HoSt	biomass gasification
20	Mr M. Kanaar	Nuon	biomass gasification
21	Mr A. Van Dongen	Nuon (formerly UNA)	biomass gasification
22	Mr J. Dijkstra	SBNN	biomass gasification
23	Mr J. Van Buijtenen	TU Delft (formerly Stork)	biomass gasification
24	Mr H. Kwast	Bruins en Kwast	biomass combustion + gasification
25	Mr J. Rooijakkers + Mr G. Dijkman	Twence	biomass combustion + gasification
26	Mr P.-P. Schouwenberg	Essent	biomass combustion + gasification
27	Mr J. Gelderblom	Agro AdviesBuro	biomass combustion
28	Mrs M. Aarts-Colaris	BES	biomass combustion
29	Mr W. Hermans	BioOne Group	biomass combustion
30	Mr R. Van Hutten	Cogas Energie	biomass combustion
31	Mr C. Munsters	DEP	biomass combustion
32	Mr R. Remmers	Essent	biomass combustion
33	Mr P. Van Roy	HIS	biomass combustion
34	Mr W. Van Lieshout	HVC	biomass combustion
35	Mr D. Schiricke	Nuon	biomass combustion

Table A-1 provides an overview of the interviewees. Apart from the interviews and document reviews, two biomass gasification plants and four biomass combustion plants were visited (see table A-2). Although these visits did not directly contribute to the data collection, they were helpful in obtaining a better impression of the technology.

Table A-2 Overview of visits to bio-energy plants.

Location of the plant	Type of plant
Geertuidenberg (Amer-project)	large-scale biomass gasification plant, operational at the time of the visit
Bladel	small-scale biomass gasification plant, closed down
Hengelo	large-scale biomass combustion plant, under construction
Schijndel	small-scale operational biomass combustion plant
De Lier	small-scale operational biomass combustion plant
Sittard	small-scale biomass combustion plant, operational at the time of the visit

Summary

Uncertainty and entrepreneurial action
The role of uncertainty in the development of emerging energy technologies

There is an increasing awareness among scholars, policy makers and society at large of the environmental problems caused by the existing energy system. To counteract these problems and achieve a more sustainable future, new technologies that are more sustainable than the existing technologies need to be developed and implemented on a large scale. More sustainable technologies include both energy-efficient technologies (i.e. technologies that still use fossil fuels, but more efficiently than the existing technologies) as well as renewable energy technologies (i.e. technologies that are fuelled by renewable energy sources like wind, biomass, hydropower or solar power).

One of the starting points of this thesis is that the development and implementation of emerging, more sustainable energy technologies cannot take place without the involvement of entrepreneurs. The role of the entrepreneur is to turn the potential of new knowledge, networks and markets into concrete actions to generate and take advantage of new business opportunities (Hekkert, Suurs et al. 2007). This role is not fulfilled by a single actor but by multiple, different types of actors, including both technology developers and technology adopters (buyers and users of the technology), new entrants as well as incumbent companies. Through their actions, these various types of entrepreneurs help turn the outcomes of basic R&D activities into commercial technological products that can be implemented on a large scale.

An important characteristic of innovation decisions concerning emerging technologies is that they inherently involve many uncertainties. In this thesis, the term 'uncertainty' is defined broadly as "*any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system*" (Walker, Harremoes et al. 2003, p. 5). These uncertainties play a key role, since they greatly influence the innovation decisions and actions of entrepreneurs. However, the relationship between uncertainty and entrepreneurial action is not straightforward. On the one hand, the high degree of uncertainty signifies the large range of opportunities that a new technology has to offer. On the other hand, however, this uncertainty poses a threat of not knowing what comes next and not being able to *ex ante* determine the success or failure of a technological path. In other words, uncertainty can both stimulate and discourage entrepreneurs in terms of developing and implementing emerging technologies.

The central aim of this thesis is to gain a better understanding of the role of perceived uncertainties in the development and implementation of emerging, more sustainable energy technologies. More specifically, this thesis aims to address four issues that have not yet received sufficient attention in the innovation literature. First, scholars have recently argued that relatively little work has attempted to clearly define and analyze the different types of uncertainties encountered in innovation processes. Second, there are still too few studies that analyze how perceived uncertainties influence the interrelated entrepreneurial actions of both technology developers and technology adopters. The reason for this is that previous innovation studies

have either focused on the system level or on the level of individual firms. A shortcoming of the system-level studies is that they provide little insight into the perspective of the entrepreneurs, whereas the firm-level studies only focus on one type of entrepreneurs (either technology developers or adopters). A third aim is to explore whether and how perceived uncertainties and the influence of perceived uncertainties on entrepreneurial action differ for technologies in different phases of development. The literature on technology and industry life cycles argues that uncertainty is high in the early phases of technology development and decreases in later phases, as a technology matures. Since the explanatory power of the life cycle studies pertains particularly to the technology or industry, important new insights can be gained by analyzing these issues from the perspective of the entrepreneurs. The final aim of this thesis is to translate the findings into lessons that can help policy-makers and entrepreneurs to better deal with dominant uncertainties, so as to accelerate the development and implementation of more sustainable energy technologies.

The thesis consists of four case studies that each focus on a specific technology. To address the third research aim, an important criterion for the case selection is to include technologies that are in different phases of development. Four successive phases are distinguished: pre-development, take-off, acceleration and stabilization (Rotmans, Kemp et al. 2001; Van Lente, Smits et al. 2003). Since this thesis focuses on emerging technologies (as opposed to established technologies), only the first three phases are taken into account. The case selection resulted in the following set of technologies: micro-CHP (Combined generation of Heat and Power on domestic scale), biofuels (technologies for the conversion of biomass into liquid fuels that are primarily used for transportation), biomass gasification and biomass combustion (the latter two are technologies to convert biomass into electricity and heat). The following research questions are posed:

RQ1: *What are the dominant types of uncertainties as perceived by the various entrepreneurs involved in the development and implementation of micro-CHP, biofuels, biomass gasification and biomass combustion in the Netherlands?*

RQ2: *How do perceived uncertainties influence entrepreneurial action and thereby the development and implementation of these technologies?*

RQ3: *What general insights can be derived from the cases studied with respect to the influence of perceived uncertainty on entrepreneurial action in subsequent technology development phases?*

RQ4: *What are the implications for policy and management?*

Chapter 2 introduces a theoretical framework for studying the role of perceived uncertainties in socio-technological transformations (also called: 'transitions'). The framework consists of three building blocks: a typology of perceived uncertainties, a typology of actors, and a distinction between different technology development phases. The framework is based on two assumptions. The first assumption is that, depending on the type of actor, different types of uncertainty will dominate their innovation decisions. The second assumption is that different types of perceived uncertainty will dominate in different phases (pre-development, take-off, acceleration and stabilization). Perceived uncertainties are classified according to their nature (knowledge or variability), level (ranging from low to high) and source (technological, resource, competitive, supplier, consumer, and political uncertainty). The source of uncertainty can be seen as the first order classification (the 'variables'), and the nature and the level of uncertainty as the second order classification (the 'dimensions' that constitute the variable). The empirical cases primarily concentrate on the distinction between different uncertainty sources.

Chapter 3 presents the results of the first case study on the development of micro-CHP, a technology that is currently in the pre-development phase (i.e. the phase in which prototypes are developed but the technology has not yet entered the market). Data is mainly collected through interviews with the key actors. To gain more insight into the influence of perceived uncertainties on the overall transition, the micro-CHP case analyzes whether perceived uncertainties stimulate or hinder actors with respect to undertaking certain key activities essential to achieve a transition (also called "Functions of Innovation Systems" (Hekkert, Suurs et al. 2007), see Figure S-1).
The interview results show that technological and political uncertainty are the main sources of perceived uncertainty. Furthermore, the results show that technology developers and potential technology adopters (e.g. energy companies and housing organizations) react differently to perceived uncertainties. Whereas perceived uncertainties block potential adopters from taking action, perceived uncertainties do not hamper technology developers in fulfilling the role of entrepreneur. For technology developers, perceived uncertainties form an incentive to initiate all sorts of activities to manage the dominant sources of uncertainty. In reaction to technological uncertainty, technology developers invest in knowledge development (Function 2 of Figure S-1). In response to political uncertainty, technology developers initiate lobbying activities so as to create legitimacy for micro-CHP (Function 7 of Figure S-1). Since the fulfilment of these activities contributes to the well functioning of the emerging technological innovation system and since progress is still being made, it is concluded that perceived uncertainties do not hamper the development of micro-CHP in this early technology development phase.

Chapter 4 combines the outcomes of the micro-CHP case with the outcomes of the biofuels case. Biofuels technology is, just as micro-CHP, still in the pre-development phase. The biofuels case applies the same conceptual model as the micro-CHP case (see Figure S-1). However, the focus and data collection procedure differ. Whereas the micro-CHP case analyzes all six sources of uncertainty, the biofuels case focuses exclusively on one source of uncertainty that has proven to play a dominant role: political uncertainty. Furthermore, whereas the micro-CHP case provides a 'static' view of perceived uncertainties, in the biofuels case a first attempt is made to incorporate a more dynamic view on how perceived uncertainties and actor behaviour evolve over time. The data for this analysis is based on a review of grey literature (newspaper articles, professional journals, policy documents, etc.) on the developments of biofuels in the Netherlands from 1990 to 2005.
The case results show that political uncertainty plays a dominant role. In the period 1990-1995, political uncertainty is mainly caused by a lack of clear governmental policy with respect to general support for biofuels. In the period 1995-2002, governmental policy shows a clear preference for second-generation biofuels, resulting in much uncertainty about the support for

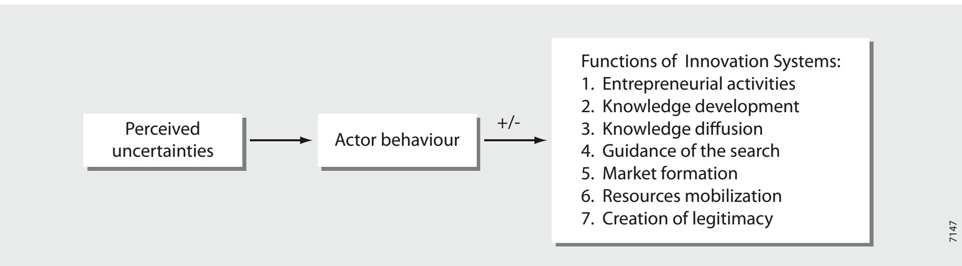


Figure S-1 Conceptual model of the micro-CHP case and the biofuels case.

first-generation biofuels. In the period 2002-2005, the Dutch government decides to support both first- and second-generation biofuels in order to meet the EU-directive demanding that the member states substitute part of their traditional transportation fuels by biofuels. As a result, uncertainty about the support for first-generation biofuels diminishes. However, entrepreneurs continue to perceive uncertainty about governmental policy, as it is unclear what type of policy instruments will be implemented to support the creation of a biofuels market. The case results show that political uncertainty greatly influences entrepreneurial action. Although the entrepreneurs undertake all sorts of lobbying activities to reduce political uncertainty (Function 7 of Figure S-1), this uncertainty (especially with respect to market creation) discourages firms from initiating entrepreneurial projects (Function 1 of Figure S-1). Since biofuels technology is approaching market introduction, this finding forms a first indication that the blocking power of perceived uncertainties on entrepreneurial action increases once a technology enters the take-off phase.

Chapter 5 reports the outcomes of the third case study on biomass gasification, a technology that has reached the take-off phase (i.e. the phase in which the emerging technology has entered the market and the first adopters start buying and using the technology). Since the biofuels case has shown that the perceived uncertainties and the actions of entrepreneurs evolve over time, the biomass gasification case aims to acquire a better understanding of how such changes come about. To this end, the biomass gasification case zooms in on entrepreneurial projects aimed to develop and implement biomass gasification plants, and applies a more dynamic model to analyze the influence of perceived uncertainty on the actions of the entrepreneurs (see Figure S-2). By conducting interviews with the involved entrepreneurs and studying grey literature, data is collected on different project stages (start-up, implementation and exploitation).
In the biomass gasification case, technology developers and technology adopters (mainly energy companies, wood processing companies, waste processing companies and farmers) collectively fulfil the role of entrepreneur. The main sources of perceived uncertainty are technological, political and resource uncertainty (biomass and financial resources). The project analyses prove that perceived uncertainties and motivation change over time under the influence of various internal and external factors in the project environment, including, among others, changes in the actor constitution, institutional change and external technological developments. Whereas the motivation of the entrepreneurs is initially strong enough to outweigh perceived uncertainties, most of the biomass gasification projects are abandoned prematurely. The termination of these projects can be explained by the frequent occurrence of negative interaction patterns between the various factors in the project environment, the different sources of perceived

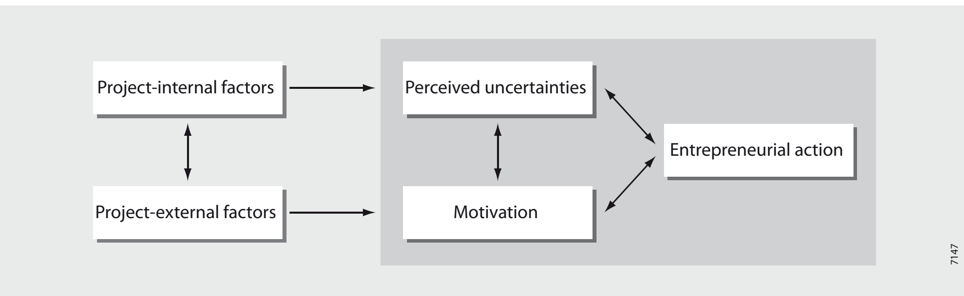


Figure S-2 Conceptual model of the biomass gasification and the biomass combustion case.

uncertainty and the motivation of the entrepreneurs. Perceived uncertainties accumulate because different uncertainty sources interact and negatively reinforce each other. In addition, various internal factors (such as the withdrawal of a project partner) and external factors (such as the liberalization of the energy market and the success of competing technologies) negatively influence the perceived uncertainties and/or the motivation of the entrepreneurs. As a result of these negative interaction patterns, perceived uncertainties increase over time while the motivation of the entrepreneurs decreases. Some entrepreneurs try to reduce perceived uncertainties by undertaking various activities such as lobbying, cooperating and knowledge-development, but only few of them succeed. Most entrepreneurs decide to stop their actions since their motivation no longer compensates for the many perceived uncertainties. Thus, the development of biomass gasification stagnated in the take-off phase.

Chapter 6 presents the results of the final case study on biomass combustion, a technology that has reached the acceleration phase (i.e. the phase in which the technology starts to diffuse rapidly). Since the biomass gasification case has demonstrated that interactions between different types of uncertainties and various factors in the project environment largely influence the decision of entrepreneurs whether or not to continue with their projects, the analysis of the biomass combustion case specifically focuses on the identification of these interactions. The same conceptual model (see Figure S-2) and data collection procedure are applied as in the biomass gasification case.
In the biomass combustion case, the role of entrepreneur is mainly fulfilled by the technology adopters (mainly energy companies, wood processing companies, waste processing companies and farmers). The main sources of perceived uncertainty are political and resource uncertainty (biomass feedstock and financial resources). As in the biomass gasification case, the biomass combustion case shows that an increase of perceived uncertainty is often triggered or intensified by factors in the project environment. Furthermore, the biomass combustion case offers several examples of negative interaction patterns between different sources of uncertainty. However, in contrast to the biomass gasification case, none of the biomass combustion projects is abandoned. The main explanations for the continuation of entrepreneurial action are found in the relatively minor importance of technological uncertainty, the positive influence of external technological developments, and the many examples of successful uncertainty management activities. These uncertainty management activities reduce the perceived uncertainties, which in turn positively influence the motivation of entrepreneurs to continue their actions. Thus, the biomass combustion projects are mainly characterized by positive interaction patterns between perceived uncertainties, motivation and entrepreneurial action.

Chapter 7 synthesizes the findings of the case studies and reflects on the quality of the research design, in order to answer research questions 1, 2 and 3. With respect to the first research question, it is concluded that political, technological and resource uncertainty are the most important uncertainty sources for the technologies studied. Political uncertainty is in all four cases a dominant source of perceived uncertainty. The importance of political uncertainty mainly stems from the frequent changes of the financial instruments aimed at stimulating more sustainable energy. Technological uncertainty plays a dominant role in the micro-CHP and biomass gasification cases, since practical experience with these emerging technologies is still lacking. Uncertainty about the mobilization of resources (including financial resources as well as feedstock) is dominant in the biomass gasification case and the biomass combustion case. The entrepreneurs involved in these cases perceive uncertainty about the availability, price and quality of biomass as well as about the mobilization of financial resources from external investors.

With respect to the second research question, the case results confirm that actors are only willing to act entrepreneurially if the uncertainties they perceive are counterbalanced by a strong motivation to engage in the development and implementation of the emerging technology. Whether or not different types of actors (technology developers or adopters) are willing to fulfil the role of entrepreneur differs across the cases, as a result of differences in motivation and perceived uncertainties. Those actors who are motivated to fulfil the role of entrepreneur try to reduce the perceived uncertainties by initiating various sorts of activities (including lobbying, cooperation or knowledge-development activities). However, these activities are not always sufficient. As a result of negative interaction patterns, perceived uncertainties can accumulate and the motivation of the entrepreneurs can decrease over time. Cross-case comparison shows that these negative interaction patterns are mainly found in the case on biomass gasification, the technology which is currently in the take-off phase. Because of these negative interaction patterns, most biomass gasification projects have been abandoned. Since biomass gasification can only reach the acceleration phase if several entrepreneurial projects manage to become a success, the development of biomass gasification has stagnated in the take-off phase.

The aim of the third research question is to discuss what general insights can be derived from the cases studied. Due to the limited number of cases and the information-processing biases of people, it remains difficult as a case study researcher to argue that the study's findings are generalizable beyond the immediate cases studied. A strategy that helps to strengthen the grounds for generalization is to compare the case study findings to similar as well as conflicting arguments put forward in the innovation literature.

The conclusion that the problems encountered in the biomass gasification case are related to the technology development phase is supported by a broad range of innovation studies that describe the phase between R&D activities and large-scale commercial application (in this thesis called the 'take-off phase') as a 'Valley of Death', as 'Innovation Gap' or as a 'Chasm'. According to this literature, many promising technologies never bridge this critical phase due to a lack of funding, due to a gap between the market for the 'early adopters' (the 'visionaries') and the 'early majority' (the 'pragmatists'), and due to the organizational problems of combining good R&D skills with good marketing skills. Since the empirical results of this research are in line with this body of literature, it seems reasonable to assume that the high failure rate of entrepreneurial projects in the biomass gasification case is related to the technology development phase. The added value of this research with respect to the above literature is that it provides more insight into the underlying dynamics that explain why so many entrepreneurial projects fail in this critical phase. This research has shown that the problems mentioned in the above-mentioned literature are not independent, but negatively reinforce each other. The many negative interaction patterns that are found in the empirical data help to better understand why so many entrepreneurs decide to abandon their activities during the take-off phase.

A rival explanation for the outcomes of the cross-case comparison is that the differences between the cases studied are related to the technological characteristics. Radical, complex innovations (such as biomass gasification) involve a higher degree of technological uncertainty than more incremental innovations (such as biomass combustion). Rather than rejecting the influence of the technology development phase on the outcomes of the cross-case comparison, the differences in technological characteristics between the cases provide a complementary explanation for the empirical findings. In other words, the higher importance of perceived technological uncertainty in the biomass gasification case as compared to the biomass combustion case is the result of both the earlier phase of development and of the higher technological complexity. Since radical innovations involve more uncertainties, they will need more time, money and effort to survive the take-off phase than incremental innovations. In the biomass gasification case, the time and resources available to experiment with the technology have proved insufficient to reduce the high level of uncertainties and the many negative interaction patterns encountered during the take-off phase.

Chapter 8 discusses the implications for policy and management (research question 4). Due to the ambiguous relationship between uncertainty and innovation, these implications are not straightforward. Acknowledging that uncertainty is an inevitable characteristic and likely even a 'sine qua non' of innovation, one realizes that policy-makers cannot and should not strive to completely eliminate the uncertainties that entrepreneurs perceive. Still, the current situation in which uncertainties hinder entrepreneurial action is not beneficial to innovation either. The policy instruments currently in place in the Netherlands to support more sustainable energy technologies are of short duration, do not provide sufficient support in the take-off phase and are too fragmented. To reduce political uncertainty and stimulate the development and implementation of these technologies, governmental policy should aim to support emerging technologies through all the successive phases of the innovation process. However, this long-term support can only become successful if two conditions are met. First, governmental support should focus on a restricted number of technologies. Second, governmental support should only be continued if substantial progress is made. To address these issues, the policy design must include arrangements for selecting and evaluating technologies. To prevent that the government is accused of 'picking winners' or 'supporting pet technologies', the government should abstain from performing technology evaluations itself. Instead, these evaluations can be delegated to an independent committee or institute.
To support the selected technologies, specific measures should be taken in each phase. In the pre-development phase, stagnation can arise as entrepreneurs wait for certainty about governmental support for the creation of a market while policy-makers wait for certainty about the outcomes of entrepreneurial action. A strategy that can help manage these uncertainties and prevent early stagnation is to enhance interaction between policy-makers, entrepreneurs and other stakeholders. By means of interaction, the different stakeholders have the opportunity to learn about the viewpoints and strategies of the other actors, to develop and discuss different scenarios and to articulate the conditions that need to be fulfilled in order for each actor to take action.
A way for government to help emerging technologies survive the take-off phase is to support a limited number of pioneer projects. In this way, a niche market can be established that provides sufficient room to experiment with the new technology and to learn how best to deal with the various sources of perceived uncertainty encountered during this phase. Governmental support for this limited selection of pioneer projects should aim to help entrepreneurs put an end to the build-up of negative interaction patterns. An independent committee may help to evaluate the risk/reward potential of entrepreneurial projects, to analyze the dominant sources of perceived uncertainty and the constraining factors in the project environment, and to identify possible solutions to ending the build-up of negative interaction patterns. Policy-makers can use this information to decide which projects to support and what tailor-made strategies to apply to increase the project's chances of success. This information may also help reduce the uncertainties that private investors perceive about energy innovation projects and thereby increase the availability of financial resources.

In the acceleration phase, uncertainties are smaller and easier to manage. Nevertheless, governmental support may still be required to reduce uncertainty about the mobilization of financial resources. However, governmental support should not continue forever. Once the new technology has acquired a sufficiently large market share, it will become easier for entrepreneurs to further mobilize financial resources from private investors. Interim progress evaluations can help to determine when governmental support can be decreased.

Samenvatting

Onzekerheid en ondernemersgedrag
De rol van onzekerheid in de ontwikkeling van opkomende energietechnologieën

Er is een groeiend bewustzijn onder wetenschappers, beleidsmakers en in de samenleving in het algemeen van de milieuproblemen die worden veroorzaakt door het huidige energiesysteem. Om deze problemen tegen te gaan en een duurzamere toekomst te bereiken, is het noodzakelijk dat nieuwe duurzame technologieën worden ontwikkeld en op grote schaal geïmplementeerd. De term duurzame technologie wordt in dit proefschrift zowel gehanteerd voor energie-efficiënte technologieën (d.w.z. technologieën die weliswaar fossiele brandstoffen gebruiken, maar efficiënter zijn dan de huidige technologieën) als voor technologieën die gebruik maken van hernieuwbare energiebronnen zoals wind, biomassa, waterkracht of zonlicht.

Een van de uitgangspunten van dit proefschrift is dat de ontwikkeling en implementatie van deze innovatieve energietechnologieën niet kan plaatsvinden zonder de betrokkenheid van ondernemers. De rol van de ondernemer is om het potentieel aan nieuwe kennis, netwerken en markten om te zetten in concrete acties met het doel om nieuwe bedrijfskansen te genereren en uit te buiten (Hekkert, Suurs et al. 2007). Deze rol wordt niet door slechts één actor vervuld, maar door meerdere, diverse typen actoren: zowel technologieontwikkelaars als technologie-adopters (kopers en gebruikers van de technologie), zowel nieuwkomers als gevestigde bedrijven. Door hun acties dragen deze verschillende typen ondernemers eraan bij dat de uitkomsten van R&D-activiteiten worden omgezet naar commerciële technologische producten die op grote schaal kunnen worden geïmplementeerd.

Een belangrijke eigenschap van innovatiebeslissingen op het gebied van opkomende technologieën is dat deze beslissingen inherent onzekerheden met zich meebrengen. In dit proefschrift wordt de term ‘onzekerheid’ breed gedefinieerd als *“elke afwijking van het onbereikbare ideaal van compleet deterministische kennis van het relevante systeem”* (Walker, Harremoes et al. 2003, p. 5). Deze onzekerheden spelen een sleutelrol, aangezien zij een sterke invloed hebben op de innovatiebeslissingen en het innovatiegedrag van ondernemers. Echter, de relatie tussen onzekerheid en ondernemersgedrag is niet eenduidig. Enerzijds staat de hoge mate van onzekerheid voor de grote verscheidenheid aan kansen die een nieuwe technologie te bieden heeft. Anderzijds vormt deze onzekerheid echter ook een bedreiging, aangezien het niet mogelijk is om te weten wat er staat te gebeuren en om vooraf het succes of falen van een technologisch pad te bepalen. Dientengevolge kunnen de onzekerheden die ondernemers ervaren (“perceived uncertainties”) hen zowel stimuleren als belemmeren om te participeren in de ontwikkeling en implementatie van opkomende technologieën.

Het hoofddoel van dit proefschrift is om meer inzicht te krijgen in de rol van onzekerheidspercepties bij de ontwikkeling en implementatie van opkomende duurzame energietechnologieën. Meer specifiek heeft dit proefschrift tot doel om zich te richten op vier kwesties die tot op heden onvoldoende aandacht hebben gekregen in de innovatieliteratuur. Allereerst hebben wetenschappers onlangs beweerd dat er relatief weinig werk is verricht op

het gebied van het scherp definiëren en analyseren van verschillende typen onzekerheden die worden ondervonden bij innovatieprocessen. Ten tweede zijn er nog altijd onvoldoende studies die analyseren hoe onzekerheidspercepties invloed hebben op de onderling verbonden acties van zowel technologieontwikkelaars als adopters. De reden hiervoor is dat de focus van eerdere innovatiestudies ofwel op het systeemniveau of op het niveau van de individuele bedrijven lag. Een tekortkoming van de studies op systeemniveau is dat deze weinig inzicht verschaffen in het perspectief van de ondernemers, terwijl de studies op bedrijfsniveau zich slechts richten op één type ondernemer (of de technologieontwikkelaar of de adopter). Een derde doel is om te onderzoeken of en zo ja hoe onzekerheidspercepties verschillen voor technologieën in verschillende fasen van ontwikkeling. De literatuur over technologische en industriële levenscycli betoogt dat onzekerheid hoog is in de vroege fasen van technologieontwikkeling en afneemt in latere fasen, naarmate de technologie zich verder ontwikkelt. Aangezien deze levenscyclus studies de ontwikkeling van onzekerheden in de tijd voornamelijk verklaren vanuit technologische of industriële aspecten, kunnen er belangrijke nieuwe inzichten worden gewonnen door het bestuderen van deze kwesties vanuit het perspectief van de ondernemers. Het laatste doel is om uit dit onderzoek lessen te trekken voor beleidsmakers en ondernemers om beter met onzekerheden om te gaan en zo de ontwikkeling en implementatie van duurzame energietechnologieën te versnellen.
Dit proefschrift bestaat uit vier case studies die elk gericht zijn op een specifieke technologie. Met betrekking tot het derde onderzoeksdoel is het voor de case selectie van belang om technologieën te selecteren die zich in verschillende ontwikkelingsfasen bevinden. Er worden vier opeenvolgende fasen onderscheiden: voorontwikkelingsfase, take-off fase, versnellingsfase en stabilisatiefase (Rotmans, Kemp et al. 2001; Van Lente, Smits et al. 2003). Omdat dit proefschrift zich richt op opkomende technologieën (in tegenstelling tot gevestigde technologieën) worden alleen de eerste drie fasen meegenomen. De selectieprocedure heeft geleid tot de keuze voor de volgende set van technologieën: micro-wkk (warmtekrachtkoppelingsinstallaties voor huishoudens, ook wel HRe-ketel genoemd), biobrandstoffen (technologieën die biomassa omzetten in vloeibare brandstoffen die primair gebruikt worden voor transportdoeleinden), biomassavergassing en biomassaverbranding (de laatste twee zijn technologieën die biomassa omzetten in elektriciteit en warmte). De volgende onderzoeksvragen worden gesteld:

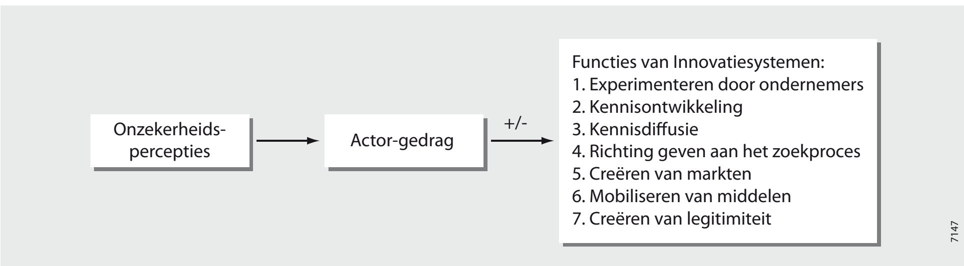
1. *Wat zijn de dominante typen onzekerheden die worden gepercipieerd door de verschillende ondernemers betrokken bij de ontwikkeling en implementatie van micro-wkk, biobrandstoffen, biomassavergassing en biomassaverbranding?*
2. *Hoe beïnvloeden onzekerheidspercepties het gedrag van ondernemers, en daardoor de ontwikkeling en implementatie van deze technologieën?*
3. *Welke algemene inzichten kunnen afgeleid worden uit de bestudeerde casussen met betrekking tot de invloed van gepercipieerde onzekerheid op ondernemersgedrag in opeenvolgende fasen van technologieontwikkeling?*
4. *Wat zijn de implicaties voor beleid en management?*

Hoofdstuk 2 introduceert een theoretisch raamwerk voor het bestuderen van de rol van onzekerheidspercepties in socio-technologische transformaties (ook wel 'transities' genoemd). Het raamwerk is opgebouwd uit drie bouwstenen: een typologie van onzekerheidspercepties, een typologie van actoren en een indeling naar verschillende fasen van technologieontwikkeling. Het raamwerk is gebaseerd op twee aannamen. De eerste aanname is dat verschillende typen onzekerheden zullen domineren in de innovatiebeslissingen van verschillende typen actoren. De tweede aanname is dat verschillende typen onzekerheden zullen domineren in verschillende fasen (voorontwikkeling, take-off, versnelling en stabilisatie). Onzekerheidspercepties worden geclassificeerd naar hun aard (kennis of variabiliteit), niveau (oplopend van laag naar hoog) en bron (technologie, middelen, concurrenten, leveranciers, consumenten en politiek). De bron van onzekerheid kan beschouwd worden als de eerste orde classificatie (de 'variabelen'), de aard en het niveau van onzekerheid als de tweede orde classificatie (de 'dimensies' van de variabelen). De empirische case studies richten zich voornamelijk op het onderscheid tussen de verschillende onzekerheidsbronnen.

Hoofdstuk 3 presenteert de resultaten van de eerste casus over de ontwikkeling van micro-wkk, een technologie die zich momenteel in de voorontwikkelingsfase bevindt (d.w.z. de fase waarin prototypen worden ontwikkeld, maar de technologie nog niet op de markt is geïntroduceerd). Interviews met de belangrijkste actoren vormen de voornaamste bron van data. Om meer inzicht te krijgen in de invloed van onzekerheidspercepties op de totale transitie, wordt in de micro-wkk case onderzocht in hoeverre onzekerheidspercepties actoren stimuleren of hinderen in het vervullen van bepaalde sleutelactiviteiten die essentieel zijn voor het bewerkstelligen van een transitie (de zogenoemde "Functies van Innovatiesystemen" (Hekkert, Suurs et al. 2007), zie Figuur S-1b).

De interviewresultaten laten zien dat technologische en politieke onzekerheid de belangrijkste bronnen van onzekerheid zijn. Daarnaast blijkt dat technologieontwikkelaars en potentiële adopters (o.a. energiebedrijven en woningcorporaties) verschillend reageren op de gepercipieerde onzekerheden. Terwijl de potentiële adopters door de onzekerheden die zij percipiëren huiverig zijn om actie te ondernemen, worden de technologieontwikkelaars er niet van weerhouden om de ondernemersrol te vervullen. Voor technologieontwikkelaars vormen de gepercipieerde onzekerheden juist een stimulans om allerlei activiteiten te initiëren om de dominante onzekerheidsbronnen zo goed mogelijk te beheersen. In reactie op technologische onzekerheid investeren technologieontwikkelaars in kennisontwikkeling (Functie 2 in Figuur S-1b). In reactie op politieke onzekerheid initiëren technologieontwikkelaars lobby activiteiten om legitimiteit te creëren voor micro-wkk (Functie 7 in Figuur S-1b). Omdat het vervullen van deze activiteiten bijdraagt aan het goed functioneren van het opkomende technologische innovatiesysteem en er vooruitgang wordt geboekt, wordt geconcludeerd dat de gepercipieerde onzekerheden in deze vroege ontwikkelingsfase de ontwikkeling van micro-wkk niet hinderen.

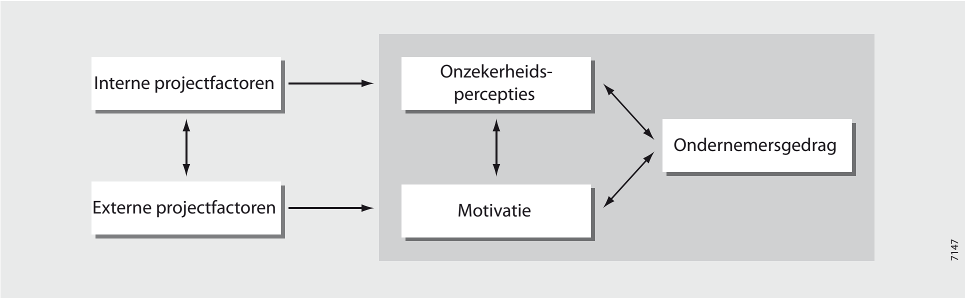
Hoofdstuk 4 combineert de uitkomsten van de micro-wkk case met de uitkomsten van de biobrandstoffen case. De technologieën waarmee biobrandstoffen worden geproduceerd bevinden zich net als micro-wkk nog in de voorontwikkelingsfase. In de biobrandstoffen case is hetzelfde conceptueel model toegepast als in de micro-wkk case (zie Figuur S-1b). Echter,



Figuur S-1b Conceptueel model van de casussen micro-wkk en biobrandstoffen.

de focus en de methode van dataverzameling verschillen. Terwijl in de micro-wkk case alle zes onzekerheidsbronnen worden geanalyseerd, richt de biobrandstoffen case zich uitsluitend op één onzekerheidsbron waarvan is aangetoond dat deze een belangrijke rol speelt: politieke onzekerheid. Daarnaast is in de micro-wkk case een 'statisch' beeld van onzekerheidspercepties gegeven, terwijl in de biobrandstoffen case een eerste poging wordt gedaan om een dynamischer beeld te schetsen van de wijze waarop onzekerheidspercepties en het gedrag van actoren zich in de tijd ontwikkelen. Deze analyse is gebaseerd op een literatuuroverzicht van grijze literatuur (krantenartikelen, vakbladen, beleidsdocumenten, etc.) over de ontwikkeling van biobrandstoffen in Nederland van 1990 tot 2005.
De resultaten van de case studie laten zien dat politieke onzekerheid een belangrijke rol speelt. In de periode 1990-1995 wordt politieke onzekerheid voornamelijk veroorzaakt door een gebrek aan helder overheidsbeleid ten aanzien van de algemene steun voor biobrandstoffen. In de periode 1995-2002 toont het overheidsbeleid een duidelijke voorkeur voor de tweede generatie biobrandstoffen, waardoor er grote onzekerheid ontstaat over steun voor de eerste generatie biobrandstoffen. In de periode 2002-2005 besluit de Nederlandse overheid zowel de eerste als de tweede generatie biobrandstoffen te steunen, om te kunnen voldoen aan de EU-richtlijn die voorschrijft dat de lidstaten een deel van de traditionele transportbrandstoffen vervangen door biobrandstoffen. Dit heeft tot gevolg dat onzekerheid over steun voor de eerste generatie biobrandstoffen afneemt. Ondernemers blijven echter onzekerheid ervaren over het overheidsbeleid, omdat het nog steeds onduidelijk is welk type instrumenten geïmplementeerd zal worden om een markt voor biobrandstoffen te creëren. De case resultaten laten zien dat politieke onzekerheid grote invloed heeft op ondernemersgedrag. Hoewel ondernemers diverse lobby activiteiten ondernemen om politieke onzekerheid te reduceren (Functie 7 van Figuur S-1b), blijft deze onzekerheid (m.n. onzekerheid over marktcreatie) ondernemers ervan weerhouden om projecten te starten (Functie 1 van Figuur S-1b). Omdat biobrandstoffentechnologie bijna rijp is voor marktintroductie, vormt deze bevinding een eerste aanwijzing dat de remmende kracht van gepercipieerde onzekerheden op ondernemersgedrag toeneemt zodra de technologie de take-off fase betreedt.

Hoofdstuk 5 rapporteert over de uitkomsten van de derde case studie over biomassavergassing, een technologie die zich bevindt in de take-off fase (de fase waarin de opkomende technologie de markt heeft betreden en de eerste adopters de technologie gaan kopen en gebruiken). Omdat de biobrandstoffen casus heeft laten zien dat onzekerheidspercepties en ondernemersgedrag in de tijd veranderen, tracht de biomassavergassing case meer inzicht te verschaffen in de wijze waarop zulke veranderingen tot stand komen. Hiertoe wordt in deze case ingezoomd op ondernemersprojecten die als doel hebben om biomassavergassingsinstallaties te ontwikkelen en implementeren en wordt een meer dynamisch model gehanteerd om de invloed van onzekerheidspercepties op ondernemersgedrag te analyseren (zie Figuur S-2b). Door middel van interviews met de betrokken ondernemers en het bestuderen van grijze literatuur wordt informatie verzameld over de verschillende projectstadia (initiatie, implementatie, exploitatie).
In de biomassavergassing case vervullen technologieontwikkelaars en adopters (voornamelijk energiebedrijven, houtindustrie, afvalverwerkingsbedrijven en boeren) gezamenlijk de ondernemersrol. De belangrijkste bronnen van gepercipieerde onzekerheid zijn onzekerheid over technologie, politiek en middelen (biomassa en financiële middelen). De projectanalyses laten zien dat onzekerheidspercepties en motivatie in de tijd veranderen onder invloed van verschillende interne en externe projectfactoren (factoren in de interne en externe projectomgeving), zoals onder meer veranderingen in de actorsamenstelling, institutionele veranderingen en externe



Figuur S-2b Conceptueel model van de casussen biomassavergassing en biomassaverbranding.

technologische ontwikkelingen. Hoewel de motivatie van de ondernemers aanvankelijk sterk genoeg is om op te wegen tegen de gepercipieerde onzekerheden, worden de meeste biomassavergassingsprojecten vroegtijdig stopgezet. De beëindiging van deze projecten kan verklaard worden door de veelvoorkomende negatieve interactiepatronen tussen de verschillende projectfactoren, de verschillende onzekerheidsbronnen en de motivatie van de ondernemers. Gepercipieerde onzekerheden stapelen zich op, omdat verschillende onzekerheidsbronnen op elkaar inwerken en elkaar negatief versterken. Bovendien hebben verschillende interne factoren (zoals de terugtrekking van een van de projectpartners) en externe factoren (zoals de liberalisering van de energiemarkt en het succes van concurrerende technologieën) een negatieve invloed op de onzekerheidspercepties en/of motivatie van de ondernemers. Als gevolg van deze negatieve interactiepatronen, nemen de gepercipieerde onzekerheden in de tijd toe terwijl de motivatie afneemt. Een aantal ondernemers probeert onzekerheden te reduceren door allerlei activiteiten te ondernemen, zoals lobbyen, samenwerken en kennis ontwikkelen, maar slechts enkele van hen slagen daarin. De meeste ondernemers besluiten hun activiteiten te beëindigen, omdat hun motivatie niet langer opweegt tegen de vele onzekerheden die worden gepercipieerd. Daardoor is de ontwikkeling van biomassavergassing gestagneerd in de take-off fase.

Hoofdstuk 6 presenteert de resultaten van de laatste case studie over biomassaverbranding, een technologie die de versnellingsfase heeft bereikt (de fase waarin een snelle diffusie van de technologie plaatsvindt). Omdat de biomassavergassing case heeft laten zien dat interacties tussen verschillende typen onzekerheden en verschillende projectfactoren grote invloed hebben op de beslissingen van ondernemers om al of niet door te gaan met hun projecten, richt de analyse in de biomassaverbranding case zich specifiek op het identificeren van deze interacties. Het conceptueel model (zie Figuur S-2b) en de procedure van dataverzameling die hierbij worden gehanteerd zijn identiek aan de biomassavergassing case.
In de biomassaverbranding case wordt de ondernemersrol voornamelijk vervuld door adopters (voornamelijk energiebedrijven, houtindustrie, afvalverwerkingsbedrijven en boeren). De belangrijkste onzekerheidsbronnen zijn onzekerheid over politiek en middelen (biomassa en financiële middelen). Evenals in de biomassavergassing case, blijkt in de biomassaverbranding case dat een toename van gepercipieerde onzekerheden veelal teweeg wordt gebracht of wordt versterkt door factoren in de projectomgeving. Bovendien toont de biomassaverbranding case diverse voorbeelden van negatieve interactiepatronen tussen verschillende onzekerheidsbronnen. Echter, in tegenstelling tot de biomassavergassing case, is geen van de biomassaverbrandingsprojecten stopgezet. De voornaamste verklaringen voor de voortzetting van ondernemersactiviteiten worden afgeleid uit het relatief beperkte belang van

technologische onzekerheid, de positieve invloed van externe technologische ontwikkelingen en de vele voorbeelden van succesvolle activiteiten op het gebied van onzekerheidsmanagement. Deze onzekerheidsmanagement-activiteiten leiden tot een afname van de gepercipieerde onzekerheden, wat vervolgens een positieve invloed heeft op de motivatie van ondernemers om hun activiteiten voort te zetten. Hierdoor worden de biomassavergassingsprojecten voornamelijk gekenmerkt door positieve interactiepatronen tussen onzekerheidspercepties, motivatie en ondernemersgedrag.

Hoofdstuk 7 voegt de resultaten van de case studies samen en reflecteert op de kwaliteit van de onderzoeksopzet, met als doel om onderzoeksvragen 1, 2 en 3 te beantwoorden. Met betrekking tot de eerste onderzoeksvraag wordt geconcludeerd dat politieke onzekerheid, technologische onzekerheid en onzekerheid over middelen de belangrijkste onzekerheidsbronnen zijn voor de bestudeerde technologieën. Politieke onzekerheid wordt in alle vier de cases als een dominante bron van onzekerheid gepercipieerd. Het belang van politieke onzekerheid komt voornamelijk door de vele veranderingen van de financiële instrumenten ter stimulering van duurzame energie. Technologische onzekerheid speelt een belangrijke rol in de casussen over micro-wkk en biomassavergassing, omdat er bij deze opkomende technologieën nog een gebrek is aan praktijkervaring. Onzekerheid over het mobiliseren van middelen (zowel wat betreft financiële middelen als brandstoffen) is dominant in de casussen over biomassavergassing en biomassaverbranding. De betrokken ondernemers percipiëren zowel onzekerheid over de beschikbaarheid, prijs en kwaliteit van biomassa als over het mobiliseren van financiële middelen van externe investeerders.

Met betrekking tot de tweede onderzoeksvraag, bevestigen de case resultaten dat actoren alleen bereid zijn om ondernemerschap te vertonen als de onzekerheden die zij percipiëren worden gecompenseerd door een sterke motivatie om te participeren in de ontwikkeling en implementatie van de opkomende technologie. Of bepaalde typen actoren (technologieontwikkelaars of adopters) bereid zijn om de rol van ondernemer te vervullen verschilt tussen de casussen, als gevolg van verschillen in motivatie en onzekerheidspercepties. De actoren die bereid zijn om de ondernemersrol te vervullen proberen onzekerheden te reduceren door verschillende soorten activiteiten te initiëren (waaronder lobby activiteiten, samenwerkingsactiviteiten en kennisontwikkelingsactiviteiten). Echter, deze activiteiten zijn niet altijd toereikend. Als gevolg van negatieve interactiepatronen kunnen gepercipieerde onzekerheden zich opstapelen en kan de motivatie van ondernemers na verloop van tijd afnemen. Een onderlinge vergelijking van de casussen toont aan dat deze negatieve interactiepatronen voornamelijk gevonden worden in de case over biomassavergassing, de technologie die momenteel in de take-off fase is. Vanwege deze negatieve interactiepatronen zijn de meeste biomassavergassingsprojecten stopgezet. Omdat biomassavergassing alleen de versnellingsfase kan bereiken als meerdere projecten een succes worden, is de ontwikkeling van biomassavergassing in de take-off fase gestagneerd.

Het doel van de derde onderzoeksvraag is om te bediscussiëren welke generieke inzichten afgeleid kunnen worden uit de bestudeerde casussen. Als gevolg van het beperkte aantal casussen en de onvermijdbare vertekening die ontstaat tijdens het verwerken van informatie door de onderzoeker, blijft het als case studie onderzoeker lastig om te betogen dat de onderzoeksbevindingen generaliseerbaar zijn naar situaties buiten de bestudeerde casussen. Een strategie die beoogt de generaliseerbaarheid te versterken, bestaat uit het vergelijken van de bevindingen uit de case studies met vergelijkbare en conflicterende argumenten uit de innovatieliteratuur.

De conclusie dat de problemen die ondervonden werden in de biomassavergassing case gerelateerd zijn aan de technologieontwikkelingsfase, wordt ondersteund door diverse innovatiestudies die de fase tussen R&D en grootschalige toepassing (in dit proefschrift aangeduid als 'take-off fase') beschrijven met de termen 'Valley of Death' ('Vallei des doods'), 'Innovation Gap' ('Innovatiekloof') en 'Chasm' ('Kloof'). Volgens deze literatuur slagen vele veelbelovende technologieën er nooit in om deze kritieke fase te overbruggen, als gevolg van een gebrek aan financiering, als gevolg van het bestaan van een kloof tussen de 'early adopters' (de 'visionairs' die als eerste een technologie adopteren) en de 'early majority' (de middengroep bestaande uit 'pragmatisten') en als gevolg van de organisatorische problemen rondom het combineren van goede vaardigheden op het gebied van R&D met goede marketingvaardigheden. Aangezien de empirische resultaten van dit onderzoek in overeenstemming zijn met deze literatuur, lijkt het aannemelijk om te betogen dat het hoge falingspercentage van ondernemersprojecten in de biomassavergassing case gerelateerd is aan de technologieontwikkelingsfase. De toegevoegde waarde van dit onderzoek ten opzichte van bovengenoemde literatuur is dat meer inzicht wordt verschaft in de onderliggende dynamiek die verklaart waarom zoveel ondernemersprojecten in deze kritieke fase falen. Dit onderzoek heeft aangetoond dat de problemen die in bovengenoemde literatuur worden beschreven niet onafhankelijk zijn, maar elkaar negatief versterken. De vele negatieve interactiepatronen die in de empirische data gevonden zijn helpen beter te begrijpen waarom zo veel ondernemers besluiten om hun activiteiten stop te zetten tijdens de take-off fase.

Een rivaliserende verklaring voor de uitkomsten van de case vergelijking is dat de verschillen tussen de cases gerelateerd zijn aan de technologische karakteristieken. Radicale, complexe innovaties (zoals biomassavergassing) brengen een grotere mate van technologische onzekerheid met zich mee dan meer incrementele innovaties (zoals biomassaverbranding). In plaats van de invloed van de technologieontwikkelingsfase op de uitkomsten van de case vergelijking te weerleggen, bieden de verschillen in technologische karakteristieken tussen de casussen een aanvullende verklaring voor de empirische bevindingen. In andere woorden, het grote belang van gepercipieerde technologische onzekerheid in de biomassavergassing case in vergelijking met de biomassaverbranding case is het resultaat van zowel de vroege ontwikkelingsfase als de hoge mate van technologische complexiteit. Omdat radicale innovaties meer onzekerheden met zich meebrengen, zullen zij meer tijd, geld en inspanning nodig hebben om de take-off fase te overleven dan incrementele innovaties. In de biomassavergassing case waren de tijd en middelen die beschikbaar waren om met de technologie te experimenteren ontoereikend om de hoge mate van onzekerheid en de vele negatieve interactiepatronen die werden ondervonden in de take-off fase te reduceren.

Hoofdstuk 8 bediscussieert de implicaties voor beleid en management (onderzoeksvraag 4). Als gevolg van de ambigue verhouding tussen onzekerheid en innovatie zijn deze implicaties gecompliceerd. Erkennend dat onzekerheid een onvermijdelijk kenmerk en mogelijk zelfs een 'sine qua non' is van innovaties, komt men tot het besef dat beleidsmakers er niet naar kunnen of moeten streven om de onzekerheden die ondernemers percipiëren volledig te elimineren. Echter, de huidige situatie waarin onzekerheden belemmerend werken op ondernemerschap is evenmin bevorderlijk voor innovatie. De beleidsinstrumenten die momenteel in Nederland van kracht zijn om duurzame energietechnologieën te steunen zijn van korte duur, bieden onvoldoende steun in de take-off fase en zijn te gefragmenteerd. Om politieke onzekerheid te reduceren en de ontwikkeling en implementatie van deze technologieën te stimuleren, moet overheidsbeleid erop gericht zijn om opkomende technologieën door alle opeenvolgende fasen van het innovatieproces te steunen. Echter, dit lange-termijn beleid kan alleen succesvol worden als er aan twee voorwaarden wordt voldaan. In de eerste plaats moet overheidssteun zich concentreren op een beperkt aantal technologieën. Ten tweede moet overheidssteun alleen worden voortgezet als er aanzienlijke voortgang is geboekt. Om dit te realiseren, moet het beleidsontwerp arrangementen bevatten voor het selecteren en evalueren van technologieën. Om te voorkomen dat de overheid wordt beschuldigd van 'picking winners' (het door de overheid aanwijzen van kansrijke technologieën) en 'supporting pet technologies' (het ondersteunen van 'lievelingstechnologieën'), moet de overheid zich ervan onthouden om zelf technologieën te evalueren. In plaats daarvan kunnen deze evaluaties worden gedelegeerd aan een onafhankelijke commissie of een onafhankelijk instituut.

Om de geselecteerde technologieën te ondersteunen, dienen er in iedere fase specifieke maatregelen getroffen te worden. In de voorontwikkelingsfase kan er stagnatie ontstaan als ondernemers wachten op zekerheid over overheidssteun voor het creëren van een markt, terwijl beleidsmakers wachten op zekerheid over de uitkomsten van ondernemersactiviteiten. Een strategie die kan helpen om deze onzekerheden te beheersen en vroegtijdige stagnatie te voorkomen, bestaat uit het versterken van de interactie tussen beleidsmakers, ondernemers en andere belanghebbenden. Door middel van interactie krijgen de verschillende belanghebbenden de gelegenheid om kennis te maken met de standpunten en strategieën van de overige actoren, om verschillende scenario's te ontwikkelen en te bediscussiëren en om naar voren te brengen welke voorwaarden er vervuld moeten worden opdat iedere actor in actie komt.

Een van de manieren waarop de overheid opkomende technologieën kan ondersteunen bij het doorstaan van de take-off fase, is om een beperkt aantal pioniersprojecten te ondersteunen. Op deze manier kan een niche markt worden gecreëerd waarin voldoende ruimte wordt geboden om te experimenteren met de nieuwe technologie en te leren hoe het beste omgegaan kan worden met de verschillende bronnen van onzekerheid die in deze fase worden gepercipieerd. De overheidssteun voor deze beperkte groep pioniersprojecten dient erop gericht te zijn ondernemers te helpen de vorming van negatieve interactiepatronen een halt toe te roepen. Een onafhankelijke commissie zou kunnen helpen om de risico/opbrengsten verhouding van de projecten van ondernemers te beoordelen, om de dominante bronnen van gepercipieerde onzekerheid te onderzoeken en om mogelijke oplossingen te identificeren om een einde te maken aan de negatieve interactiepatronen. Beleidsmakers kunnen deze informatie gebruiken om te beslissen welke projecten ondersteund dienen te worden en welke 'strategieën op maat' ingezet dienen te worden om de slagingskans van projecten te vergroten. Deze informatie kan ook helpen om de onzekerheden te reduceren die private investeerders ervaren met betrekking tot innovatieve energieprojecten, en op deze wijze bijdragen aan het vergroten van de beschikbaarheid van financiële middelen.

In de versnellingsfase zijn onzekerheden kleiner en makkelijker te managen. Desondanks kan overheidssteun nog steeds nodig zijn om onzekerheid over het mobiliseren van financiële middelen te reduceren. Echter, overheidssteun moet niet eeuwig worden voortgezet. Wanneer de nieuwe technologie eenmaal een voldoende groot marktaandeel heeft verkregen, zal het voor ondernemers makkelijker worden om meer financiële middelen van private investeerders te verkrijgen. Tussentijdse voortgangsevaluaties kunnen helpen om te bepalen wanneer overheidssteun kan worden afgebouwd.

Dankwoord

Innovatie, ondernemerschap, duurzame energie, en bovenal onzekerheid. Dat zijn de kernbegrippen waar ik mij de afgelopen jaren inhoudelijk mee bezig heb gehouden, en die daarom ook zijn terug te vinden op de omslag van dit boek. De gloeilamp staat symbool voor *innovatie*; de groene stralen uit de gloeilamp staan voor *duurzame energie*. *Ondernemerschap* wordt gekenmerkt door risicovolle investeringen en actie in plaats van stilstand. En ten slotte *onzekerheid;* het grote vraagteken dat bij elk innovatieproces opduikt.

Volgens bekende innovatiewetenschappers zijn grootschalige innovatieprocessen zelden toe te rekenen aan slechts één persoon, maar veelal het resultaat van de inzet van meerdere mensen. Dat geldt zeker ook voor het voltooien van een promotietraject. Daarom wil ik iedereen bedanken die een rol heeft gespeeld bij de totstandkoming van dit proefschrift.

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Ineke Meijer
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Curriculum Vitae

Ineke Meijer was born in Amersfoort, the Netherlands, on 28 June 1979. In 1997, she completed her secondary education at the "Stedelijk Gymnasium Johan van Oldenbarnevelt" in Amersfoort. She went abroad for a year to take advanced language courses in English (in Brighton, UK) and French (in Nice, France). In 1998, she returned to the Netherlands to start her study of Science and Innovation Management (SIM) at Utrecht University. Her specialization in the field of Energy & Materials included internships at energy company Nuon and consultancy firm Cogen Projects. She obtained her master's degree in April 2003. In October 2003, she started her PhD research. The research was conducted at the Department of Innovation and Environmental Sciences (Copernicus Institute for Sustainable Development and Innovation, Faculty of Geosciences, Utrecht University) and at the Department of Policy, Organisation, Law & Gaming (Faculty of Technology, Policy and Management, Delft University of Technology). Aside from her research, she assisted in teaching courses on the development and implementation of technological innovations, management of innovation projects and innovation policy at Utrecht University. She currently works as a postdoctoral researcher at the Policy Analysis group of the Faculty of Technology, Policy and Management at Delft University of Technology.

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