Uncertainty and entrepreneurial action in the development of environmental innovations: A case comparison on the development of biomass gasification and biomass combustion in the Netherlands.

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Abstract
The goal of this article is to increase insights into the influence of perceived uncertainties on entrepreneurial action in the field of emerging sustainable energy technologies. Starting point of the analysis is that entrepreneurs will only decide to (continue to) act if the uncertainties they perceive are counterbalanced by their motivation to engage in the development and implementation of the new technology. The empirical section consists of a cross-case comparison between the development of biomass gasification and the development of biomass combustion in the Netherlands. Since biomass combustion and biomass gasification are rather similar technologies, the socio-institutional setting and the actors involved in these cases are to a large extent identical. However, the evolution of these technologies is very different. Although in the Netherlands many entrepreneurial activities were set-up around both technologies, most biomass gasification projects were abandoned whereas most of the biomass combustion projects have managed to become successful. The similar settings of the cases combined with the contrasts in terms of the evolution of the two technologies offer good opportunities for examining what role uncertainty has played in the decisions of entrepreneurs whether or not to continue their activities. The case comparison shows some remarkable differences in the dominant sources of perceived uncertainty, the types of actors fulfilling the role of entrepreneur and their motivation to do so, the influence of internal and external factors, and the occurrence of negative and positive interaction patterns that alter the uncertainty/motivation ratio. The article reflects on the outcomes of the case comparison and discusses the implications for innovation policy.

Keywords: environmental innovation, emerging sustainable energy technologies, perceived uncertainty, entrepreneurship, innovation policy
1 Introduction

Starting point of this article is that an essential role in the development of environmental technological innovations is played by the entrepreneurs. The role of entrepreneurs 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 technologies to be implemented on a large scale. This role is not fulfilled by a single entrepreneur, but by multiple, different types of entrepreneurs: technology developers as well as adopters (buyers and users of environmental technologies), new entrants as well as incumbent companies (Van de Ven 1993; Garud and Karnøe 2003; Hekkert, Suurs et al. 2007).

Since the actions of these various types of entrepreneurs to a large extent determine whether or not environmental technological innovations are successfully developed and implemented, it is very important to gain a better understanding of the underlying factors that influence the decisions and actions of entrepreneurs. An important characteristic of innovation decisions in general, and particularly of decisions concerning emerging environmental technologies, is that they inherently involve many uncertainties (Nelson and Winter 1977; Dosi 1982; Rosenberg 1996; Jacobsson and Johnson 2000). On the one hand, uncertainty is seen as providing opportunities for entrepreneurs to make profit by engaging in innovation activities. On the other hand, though, uncertainty is seen as a threat as it signifies a lack of control over the outcomes of innovation activities. In other words, uncertainty can both stimulate and discourage entrepreneurs in terms of developing and implementing environmental technological innovations.

The goal of this article is to increase insights into the influence of perceived uncertainties on entrepreneurial action in the field of emerging sustainable energy technologies. The empirical section consists of a cross-case comparison between the development of biomass gasification and the development of biomass combustion in the Netherlands. Since biomass combustion and biomass gasification are rather similar technologies, the socio-institutional setting and the actors involved in these cases are to a large extent identical. However, the evolution of these technologies is very different. Although in the Netherlands many entrepreneurial activities were set-up around both technologies, most biomass gasification projects were abandoned whereas most of the biomass combustion projects have managed to become successful. The similar settings of the cases combined with the contrasts in terms of the evolution of the two technologies offer good opportunities for examining what role uncertainty has played in the decisions of entrepreneurs whether or not to continue their activities.

To do so, this paper builds on previous theoretical and empirical work (McMullen and Shepherd 2006; Meijer, Hekkert et al. 2007b; Meijer 2008). The basic notion of the theoretical framework is that entrepreneurs will only decide to (continue to) act if the uncertainties they perceive are
counterbalanced by their motivation to engage in the development and implementation of the new technology. This decision does not take place in a vacuum, but is influenced by various factors in the project environment. To explain why some entrepreneurs decide to stop whereas others continue their actions, one therefore needs to analyze how the perceived uncertainties and the motivation of these entrepreneurs change over time and which factors in the project environment influence these changes. The following research questions are posed:

- What are the main differences and similarities between the cases of biomass gasification and biomass combustion with respect to the influence of perceived uncertainties on entrepreneurial action?
- What lessons can be drawn from the results of the case comparison for innovation policy?
2 Perceived uncertainty and entrepreneurial action

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; Milliken 1987; Sutcliffe and Zaheer 1998; Kreiser and Marino 2002; Walker, Harremoes et al. 2003). A useful conceptualization for studying uncertainty from the perspective of entrepreneurs comes from Frances Milliken, who defines 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 or organizations organize and evaluate stimuli from the environment. This definition suggests that uncertainty cannot be measured objectively, since it is dependent on the eye of the beholder. In the remainder of this article, the term ‘uncertainty’ refers to ‘perceived uncertainty’.

In a recent article in the Academy of Management Review, Jeffrey McMullen and Dean Shepherd provide an overview of the entrepreneurship theory and introduce a new conceptual model for explaining the decision of entrepreneurs on whether or not to act under perceived uncertainty. They argue 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.

In a preceding article (Meijer, Hekkert et al. 2007b), several contributions were made to the work of McMullen and Shepherd (2006). First of all, a distinction was made between different sources of uncertainty. Since previous research has suggested that entrepreneurs react differently to different sources of uncertainty (Meijer, Hekkert et al. 2007a), it is important to identify which uncertainty sources play a key role and how these uncertainty sources influence entrepreneurial action. An apparent source of uncertainty with respect to emerging technologies is technological uncertainty. In this early phase of technological development, 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 entrepreneurs 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 (Meijer, Hekkert et al. 2006; Meijer, Hekkert et al. 2007a; Meijer 2008), the following set of uncertainty sources is proposed: technological, resource, competitive, supplier, consumer and political uncertainty (see Table 1).

Table 1: Sources of perceived uncertainty with respect to innovation decisions

<table>
<thead>
<tr>
<th>Uncertainty source</th>
<th>Description</th>
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<tbody>
<tr>
<td>Technological uncertainty</td>
<td>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.</td>
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<tr>
<td>Resource uncertainty</td>
<td>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&amp;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.</td>
</tr>
<tr>
<td>Competitive uncertainty</td>
<td>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.</td>
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<tr>
<td>Supplier uncertainty</td>
<td>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.</td>
</tr>
<tr>
<td>Consumer uncertainty</td>
<td>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, and, in general, uncertainty about the long-term development of the demand over time.</td>
</tr>
<tr>
<td>Political uncertainty</td>
<td>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.</td>
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The second contribution to the work of McMullen and Shepherd (2006), related to the influence of internal and external factors. The decisions of entrepreneurs to engage in the development and implementation of emerging technologies do not take place in a vacuum, but are influenced by the context in which these decisions are made. Both the internal and the external environment of a project (such as the constitution of actors involved, the institutional setting or the state of technological development) can greatly affect the entrepreneur’s perception of uncertainties and/or his motivation to take action. Therefore, the conceptual model was extended so as to include the critical factors in the internal and external project environment (see left-hand side of Figure 1).¹

¹ Note that the conceptual model does not intend to include all factors influencing the innovation decisions of entrepreneurs, but only 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.
Figure 1: Conceptual model relating entrepreneurial action to perceived uncertainties, motivation and internal and external factors

Third, a more dynamic perspective was added. Since the article of McMullen and Shepherd (2006) focuses only on the initial decision of an entrepreneur to engage in a particular action, no explanation was provided for the fact that many entrepreneurial activities are stopped prematurely. We therefore proposed to apply a dynamic analysis of the influence of uncertainty on entrepreneurial action, so as to acknowledge that entrepreneurs constantly reassess their decision to take action in the development and implementation of an emerging technology (Meijer, Hekkert et al. 2007b). We argued that perceived uncertainties and motivation will change over time under the influence of changes in the internal and external project-environment, previous actions, and so on (see double-sided arrows in Figure 1). To explain why some entrepreneurs decide to stop whereas other continue their actions, one therefore needs to analyze how the perceived uncertainties and motivation of these entrepreneurs change over time and which factors influence these changes.
3 Methodology

The empirical section of this article contains the results of a cross-case comparison on the development of biomass gasification and biomass combustion in the Netherlands.

3.1 Data collection

The two cases focus only on stand-alone plants for combined generation of heat and electricity (CHP) out of biomass. Within each of the cases, several development and implementation projects were studied over time. From the total population of Dutch biomass gasification projects (including both terminated and ongoing projects, both small scale projects of 1-5 MW and large-scale projects of 20 MW 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 (see Figure 2). In contrast to the biomass gasification case, none of the biomass combustion projects was terminated after several years. Those biomass combustion projects that were terminated, were of such a short duration that the actors involved had difficulty recalling the projects and their perceptions of uncertainty regarding these projects. Therefore, the biomass combustion case consists only of ongoing projects (see Figure 3).

Data was collected by conducting 25 interviews and reviewing grey literature (policy documents, project reports, newspaper articles, etc.). The main group of interviewees consisted of the entrepreneurs who initiated the projects (mostly technology developers, energy companies, wood or waste processing companies and farmers). Apart from the entrepreneurs, also some researchers and policy makers who have a broad overview of the developments in the Netherlands were interviewed.

To categorize the data, a distinction was made between three consecutive project stages: start-up, implementation and exploitation. The start-up stage ends when construction of the plant starts, and the implementation stage ends when the plant is operational. For each project, a detailed chronological description was constructed, focusing on the entrepreneurs’ motivations, their perceived uncertainties, the decisions on whether or not to continue, the internal or external factors influencing these decisions, and the actions taken. These project descriptions were then used to identify the main differences and similarities between the two cases.

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2 Combined gasification of coal and biomass and co-firing of coal and biomass are excluded from the analysis. In addition, plants that only produce heat (no electricity) are excluded.

3 We tried to include all gasification 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.
3.2 Brief introduction to the cases

Below, a brief overview of the two cases is given. A more detailed description of the individual cases can be found in (Meijer, Hekkert et al. 2007b; Meijer 2008).

3.2.1 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 \( \text{H}_2 \)) 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 and still in an early stage of development. 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 Dutch biomass gasification projects reported in (Meijer, Hekkert et al. 2007b), only one project is still on-going (see Figure 2). As a result, the development of biomass gasification has (temporarily) stagnated.

**Figure 2: Timeline of biomass gasification projects**
### 3.2.2 Biomass combustion

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 reported in (Meijer 2008; Meijer 2008b), 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) (see Figure 3).

**Figure 3: Timeline of biomass combustion projects**
4 Results

The detailed descriptions of the biomass gasification and the biomass combustion projects showed that perceived uncertainties play an important role in the decision on whether or not to (continue to) act entrepreneurially. The empirical outcomes of both cases supported the argument of McMullen and Shepherd (2006) that entrepreneurs will decide to act only if their motivation is strong enough to counterbalance the perceived uncertainties. The cases furthermore showed that perceived uncertainties and motivation change over time. These changes are the result of positive and negative interaction patterns between the different variables in the conceptual model (sources of uncertainty, internal and external factors, motivation, entrepreneurial action). However, the two cases differed with respect to what types of interaction patterns (i.e. positive or negative) dominated. This section first describes how the two cases differ with respect to the build-up of negative and positive interaction patterns (4.1). We then describe the similarities and differences between the two cases with respect to the dominant sources of perceived uncertainty (4.2), the type of actors fulfilling the role of entrepreneur and their motivation to do so (4.3), and the critical factors in the internal and external project environment that have influenced the perceived uncertainties and motivation of the entrepreneurs (4.4). For each of these elements, we discuss how the differences between the two cases have contributed to the continuation or termination of entrepreneurial action. Table 2 summarizes the main results of the case comparison.

4.1 Negative versus positive interaction patterns

4.1.1 The gasification case: entrepreneurial activities terminated

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. 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 kinds of negative interaction patterns. An example, based on the biomass gasification project in Hengelo (see (Meijer, Hekkert et al. 2007b)), is graphically represented in Figure 4.
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\textsuperscript{4}, the delays also resulted in a decrease 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. As a result, the project was abandoned.

A distinction can be made between two types of negative interactions. First, negative interactions can occur between different sources of perceived uncertainty, meaning that one source of uncertainty directly or indirectly results in an increase of another source of uncertainty. For instance, uncertainty about the mobilization of financial resources was frequently influenced by the uncertainty that investors perceived about the performance of biomass gasification technology. This technological uncertainty made investors 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, different sources of uncertainty reinforced each other and perceived uncertainties accumulated. Second, negative interactions can emerge between (internal or external) factors in the project environment and perceived uncertainty. An increase of perceived uncertainties in the biomass gasification projects was often triggered or intensified by factors such as the liberalization of the energy market or changes in the constitution of actors involved.

Although the biomass gasification case also showed some examples of entrepreneurs who tried to reduce perceived uncertainties, it was lost labour. The negative interaction patterns dominated. Since the entrepreneurs did not succeed in stopping these negative interaction patterns and their motivation

\textsuperscript{4} The license was only valid for a trial-period of three years.
no longer counterbalanced the many perceived uncertainties, most biomass gasification projects were abandoned prematurely.

4.1.2 The combustion case: entrepreneurial activities continued

An interesting conclusion from the biomass combustion case was that most projects were characterized by a combination of both negative and positive interaction patterns (Meijer 2008b). Although the projects in which negative interaction patterns occurred progressed less smoothly than the projects in which these negative interaction patterns were absent, none of the biomass combustion projects was abandoned. An important explanation for this is that the negative interaction patterns were not as dominant as the positive interaction patterns which were found. The empirical data contained many instances in which perceived uncertainties motivated the entrepreneurs to initiate various uncertainty management activities. These activities (ranging from studying, experimenting and knowledge-acquisitioning to cooperating and lobbying activities) generally resulted in a reduction of perceived uncertainties, which in turn reinforced the motivation of the entrepreneurs to continue their actions. Thus, positive interaction patterns between perceived uncertainties, entrepreneurial action and motivation were established and negative interaction patterns were stopped or even prevented.

To better understand why entrepreneurial action is terminated in the biomass gasification projects and continued in the biomass combustion projects, we take a closer look at the differences and similarities between the two cases with respect to the various variables in the conceptual model.

4.2 The dominant sources of perceived uncertainty

4.2.1 Similarities and differences

In Section 2, a typology of six uncertainty sources was introduced (see Table 1). From these six sources of uncertainty described in Table 1, perceived political and resource uncertainty were found to play a dominant role in both of the cases. In the biomass gasification case, also technological uncertainty was perceived to play a dominant role.\(^5\)

In both cases, the arguments for the importance of perceived political uncertainty were mostly related to the financial instruments and the licensing procedure. Over the past decades, the Dutch government has made several, often unexpected, changes to the financial instruments. These

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\(^5\) The remaining sources of uncertainty (supplier, consumer and competitive uncertainty) were perceived to be less important. However, this finding does not imply that these uncertainty sources were not relevant. 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. To explain the behaviour of individual actors and the dynamics of individual projects, it is therefore necessary to include all six sources of perceived uncertainty into the analysis.
frequent changes have not only resulted in uncertainty about future changes to these instruments, but also about the reliability of the Dutch government in general. In addition, entrepreneurs perceive great uncertainty about the duration and outcome of the license procedure. The Dutch regulation with respect to the licensing procedure of bio-energy projects is very complex, partly overlapping and in some situations even conflicting (Van Ree, Gerlagh et al. 2000; Lindeman 2004; Gerlagh and Lammers 2006). This has led to uncertainty about the interpretation of the law. Moreover, the complexity of the law offered many opportunities for neighbours and environmental organizations to object to the license and thereby to delay or even obstruct the construction of a plant. Uncertainty about the duration and outcome of the licensing procedure is of great importance to the entrepreneurs, 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 importance of resource uncertainty in the biomass gasification case and the biomass combustion case was mainly related to feedstock and financial resources (and to a much lesser extent to knowledge resources). Perceived uncertainty with respect to feedstock is mainly the result of the newness and instability of the biomass market. In the early 90's, when the first biomass gasification and biomass combustion projects started, 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 perceive uncertainty about the quality of biomass, since the quality of various biomass streams can differ greatly and quality standards are still lacking. Apart from uncertainty about the availability, price and quality of biomass, the entrepreneurs also perceived great uncertainty about the mobilization of financial resources both from within the firm and from external investors. Since biomass gasification was not yet a 'proven' technology, investors were reluctant to invest in development and implementation projects. The novelty of the technology also played a role in the biomass combustion case. Although the entrepreneurs perceived biomass combustion to be 'proven', external investors were still hesitant to invest in biomass combustion projects. The uncertainties that these investors perceived about the technology, the outcome of the license and subsidy application, or the availability of biomass hindered them from investing in development and implementation projects.

The two cases differed with respect to perceived technological uncertainty. Whereas technological uncertainty was found to be one of the most important sources of perceived uncertainty in the biomass gasification case, it only played a modest role in the biomass combustion case. Due to the lack of experience with biomass gasification technology, entrepreneurs perceived great uncertainty about the performance of the technology. Biomass combustion, on the contrary, was perceived by the entrepreneurs as a 'proven' technology. This perception was largely influenced by successful biomass combustion projects abroad. However, this did not imply that technological problems were absent. In fact, most of the biomass combustion projects encountered technological problems. Despite the fact that all the technological components were 'proven', the integration of these components into a
successful working plant proved to be highly-dependent on project-specific characteristics (such as the specific biomass characteristics). Surprisingly, 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 other biomass combustion plants were functioning well. The technical problems were considered to be ‘normal’ teething problems which could be solved by a process of ‘learning-by-doing’.

4.2.2 The influence on entrepreneurial action

The importance of perceived technological uncertainty affected the termination of entrepreneurial action in the biomass gasification case in several ways. First, the total level of perceived uncertainties was higher in the biomass gasification case compared to the biomass combustion case. A detailed analysis of the biomass gasification projects showed that technological uncertainty was often accompanied by other sources of uncertainty. The biomass gasification 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 addition, technological uncertainty negatively influenced other sources of uncertainty. For instance, the existence of technological uncertainty resulted in an increase of perceived uncertainty about the mobilization of financial resources needed for improvement of the technology. These negative interactions between technological uncertainty and other uncertainty sources contributed even more to an accumulation of perceived uncertainties in the biomass gasification projects. Thus, the sum of perceived uncertainties was higher and negative interaction patterns emerged more frequently in the biomass gasification case compared to the biomass combustion case.

Second, the higher importance of technological uncertainty made it more difficult to reduce perceived uncertainties. Due to 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. The different uncertainty sources often required different uncertainty management activities. While, for instance, 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. Therefore, it was more difficult to establish positive interaction patterns in the biomass gasification case.

4.3 The entrepreneurs and their motivation

4.3.1 Similarities and differences

One of the starting points of this article was that emerging technologies cannot break through without the involvement of entrepreneurs who are willing to take action under uncertainty. In this section, the
cases are compared with respect to which types of actors (i.e. technology developers or adopters) fulfilled the role of entrepreneur and what motivated these actors to take-on this entrepreneurial role.

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. The technologies are developed by the same type of companies and many of these companies implement both biomass gasification and biomass combustion plants. The same holds for the adopters of these technologies: energy companies, wood processing companies and farmers. Energy companies are mainly driven by the governmental policies to reduce CO$_2$ emissions and produce ‘renewable’ electricity. For wood processing companies and farmers, biomass gasification and biomass combustion offered good opportunities to make use of the company’s waste streams (wood residues, waste wood or manure). The energy produced could be used within the company (to save energy costs) or sold on the energy market (as additional revenues). Of this whole group of adopters, several companies were involved in both biomass gasification and biomass combustion projects.

Despite these similarities, the cases differed with respect to the role that these actors fulfilled and their motivation to do so. First, the cases differed with respect to the motivation of the adopters to fulfill the role of entrepreneur. Second, technology developers played a far more modest role in the biomass combustion case as compared to the biomass gasification case.

In the biomass gasification case, the role of entrepreneur was fulfilled by technology developers and adopters (mainly 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. Biomass gasification was generally considered to be a promising technology, since the conversion efficiency of biomass into electricity is much higher compared to 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 of technology developers and adopters were mainly based on desktop studies and personal beliefs instead of practical experience. Thus, the entrepreneurs’ motivation was more ‘emotional’-based (driven by enthusiasm) than ‘rational’-based (driven by ‘proven’ results).

The lack of practical experience and the high level of perceived uncertainties formed an important reason for technology developers and adopters to cooperate and undertake entrepreneurial activities collectively. As various scholars have noted, an important incentive for firms to cooperate is to manage high levels of uncertainty (Lambe and Spekman 1997; Hagedoorn 2002; Silipo and Weiss 2005). 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 consisting 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 plant. Another reason for cooperation was 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.

In the biomass combustion case, the role of entrepreneur was fulfilled by adopters alone. 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, these 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 carried out by a joint venture of an adopter and a technology developer, all the biomass combustion projects were undertaken 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.
4.3.2 The influence on entrepreneurial action

As described above, the motivation of entrepreneurs to engage in development and implementation projects was in both cases based on positive expectations. However, the positive expectations about biomass combustion were based on the successful results of biomass combustion projects abroad whereas the high expectations about biomass gasification were merely based on personal beliefs and desktop studies. Because the expectations about biomass gasification were not based on practical experience, they turned out to be less realistic and more ‘vulnerable’ than the expectations about biomass combustion. The development and implementation of a successful-working biomass gasification plant proved 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 biomass combustion 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 4.2.1). As a result, perceived technological uncertainty remained low and entrepreneurs remained motivated to continue their biomass combustion activities.

Above (Section 4.3.1), we described that the biomass gasification projects usually involved multiple entrepreneurs (joint entrepreneurship of technology developers and adopters collectively) whereas most biomass combustion projects were initiated by a single entrepreneur (adopters alone fulfilled the role of entrepreneur). When uncertainties are high, actors may be more willing to undertake entrepreneurial action together than to bear perceived uncertainties alone. Since gasification involved more perceived uncertainties than combustion (see Section 4.2), it is understandable that joint entrepreneurship was mostly seen in the biomass gasification case. However, this intensive type 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 article, 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. Therefore, it is no surprise that the influence of the withdrawal of a project partner was more severe in the biomass gasification case than in the biomass combustion case. In the biomass gasification projects, the withdrawal of one of the actors involved generally 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 finding suggests that
shared entrepreneurship increases the chance that projects are aborted if one of the actors involved decides to withdraw.

4.4 Critical factors in the project environment

4.4.1 Similarities and differences

The entrepreneur’s perception of uncertainties and his motivation to act are influenced by various factors in the internal and external project environment. In both cases, the factors that played an important role were the constitution of actors involved, the duration of the project, the institutional context and external technological developments. However, as explained below, the influence of these factors differed quite considerably across the cases.

4.4.2 The influence on entrepreneurial action

From the empirical cases it can be concluded that changes in the constitution of actors involved (like the withdrawal of a project partner) generally have a negative influence on the uncertainty/motivation ratio. However, due to the above-described difference in the role of entrepreneur (see Section 4.3.2), this factor had a stronger influence in the gasification case than in the combustion case. Whereas the withdrawal of a project partner only resulted in an increase of perceived uncertainties in the combustion case, it usually led to project termination in the gasification case.

With respect to the duration of the project, both cases show many examples in which delay of the project contribute to the build-up of a negative interaction pattern. In several projects, one source of perceived uncertainty resulted in a delay of the project, which in turn resulted in an increase of another source of perceived uncertainty. Apart from this direct interaction between time and perceived uncertainty, delay of the project also indirectly (by way of other factors) influenced perceived uncertainty. Good examples of this were found in the gasification project in North-Holland and in the two manure combustion projects (Meijer 2008). Because of their many delays, these projects were hindered by changes in the actor constitution (withdrawal of a project partner) as well as by institutional change (like the liberalization of the energy market or unexpected policy changes). These changes in the project environment, in turn, resulted in an increase of perceived uncertainties (like uncertainty about the mobilization of financial resources that were needed to compensate for the long duration of the project), which subsequently led to further delays (the additional time needed to reduce resource uncertainty), and so on. Thus, the long duration of a project

6 Another critical factor in the biomass combustion case is external resistance from environmental organizations and neighbours. However, this factor only played a role in the two manure combustion projects and seems more related to the scale of the projects than to the technology used. Whereas the two manure gasification projects were small-scale (farm-scale) projects, the two manure combustion projects were both large-scale projects for conversion of hundreds of thousands tons of manure per year.
increases the chance that factors in the internal or external project environment start to interfere with the project.

As long as the motivation of entrepreneurs is strong enough to counteract the increased level of perceived uncertainties, these negative interactions not have to result in the termination of entrepreneurial action. In the biomass gasification case, we noticed that delay of the project was often accompanied by a decrease of the entrepreneurs’ motivation. One of the explanations for this is that the expectations about the development and implementation of biomass gasification were less realistic than in the biomass combustion case (see Section 4.3.2). Another explanation is that some gasification projects (Bladel and Hengelo) were confronted with strict deadlines, since these projects received a temporary license for a trial-period of only three years. The time available for the development and implementation of a successful-working plant was too limited in proportion to the level of perceived uncertainties. The confrontation with the strict deadline negatively influenced the motivation of the entrepreneurs. Rather than applying for a new license, the entrepreneurs of these projects abandoned their gasification activities when the validity duration of the temporarily license came to an end. In the biomass combustion project in De Lier, on the other hand, the governmental authorities 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. 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 in which all attempts to solve the technological problems had failed, the governmental authorities decided to put an end to the situation. But even then, the governmental authorities gave the entrepreneurs the opportunity to continue the project by building a new installation. Thanks to the cooperative behaviour of the governmental authorities, this project has not been abandoned. Thus, the imposition of strict deadlines can diminish the motivation to continue entrepreneurial action, as the time needed to develop and implement emerging technologies is often underestimated.

A final remarkable difference between the two cases, is the influence of 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 so-called Technological Innovation System (Carlsson and Stanckiewicz 1991; Hekkert, Suurs et al. 2007)) has a strong impact on entrepreneurial action.

Table 2: Main results of the case comparison

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

The cross-case comparison showed that the biomass gasification case was the most problematic case, since most entrepreneurial activities were abandoned. The termination of these projects can be explained by the frequent occurrence of negative interaction patterns between the various different variables in the conceptual model (internal and factors in the project environment, sources of perceived uncertainty, motivation and entrepreneurial action). 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 decided to terminate their biomass gasification activities. As a result, the development of biomass gasification has (temporarily) stagnated. In the biomass combustion case, none of the projects was abandoned. Perceived uncertainties motivated the entrepreneurs to initiate various uncertainty management activities. These activities generally resulted in a reduction of perceived uncertainties, which in turn reinforced the motivation of the entrepreneurs to continue their actions. Thus, positive interactions were established and negative interaction patterns were stopped or even prevented. In this final section, we reflect on these outcomes and discuss the implications for innovation policy.

At the moment of data collection, biomass gasification was still in the take-off phase (the phase in which the first adopters start buying and using the technology), while biomass combustion had reached the acceleration phase (the phase in which a strong diffusion of the new technology takes place) (Rotmans, Kemp et al. 2001; Van Lente, Smits et al. 2003; Meijer 2008). Since biomass gasification was in an earlier phase of technology development compared to biomass combustion, the question arises whether the outcomes of the cross-case comparison can be attributed to the technology development phase. 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)). According to the above-mentioned studies, many promising technologies don’t survive the take-off phase because of a lack of funding, the difficulties of bridging the gap between the market for the ‘early adopters’ and the ‘early majority’, and the organizational problems of combining good R&D skills with good marketing skills (see (Meijer 2008) for a more detailed account). In the light of these studies, it seems reasonable to assume that the high percentage of abandoned entrepreneurial projects in the biomass gasification case is related to the technology development phase.
An important alternative explanation for the empirical outcomes stems from the different technological characteristics of biomass gasification and biomass combustion technology. Innovation scholars have argued that radical, complex technological innovations involve a higher degree of technological uncertainty than more incremental innovations (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 was related to the low technological complexity. However, when taking a closer look at the individual projects (see (Meijer, Hekkert et al. 2007b; Meijer 2008)), it becomes clear that not all biomass gasification projects failed and not all biomass combustion projects progressed smoothly. 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 and commercially viable 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 difference in technological complexity not so much rejects the influence of the technology development phase on the outcomes of the cross-case comparison, but rather provides 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.

This article brings forward some important problems that deserve more attention by policy-makers. First, both empirical cases show that political uncertainty is one of the most dominant sources of perceived uncertainty hindering entrepreneurial action. 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 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 sustainable energy technologies in the Netherlands.
Second, the biomass gasification case showed that entrepreneurs often abandon their projects in the take-off phase due to the high level of perceived uncertainty and the many negative interaction patterns that are encountered in this phase. To increase the chance that emerging sustainable energy technologies are successfully developed and implemented, innovation policy should specifically focus on supporting entrepreneurial action in the take-off phase. Since the policy instruments currently in place in the Netherlands to support sustainable energy technologies mainly focus on the phases before and after the take-off phase (Bain & Company 2006; Energy Valley 2006; Algemene Energieraad 2007), additional policy measures for the take-off phase are needed.

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. 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 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. To illustrate, the negative interaction pattern encountered in the biomass gasification project in Hengelo (see Figure 4) 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.

Finally, the biomass combustion case showed that governmental support remains important even for technologies that have managed to reach the acceleration phase. 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 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 for technologies 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.
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7 References


