Technological Forecasting & Social Change 77 (2010) 1222–1236

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The influence of perceived uncertainty on entrepreneurial action in the transition to a low-emission energy infrastructure: The case of biomass combustion in The Netherlands

I.S.M. Meijer [a,*], J.F.M. Koppenjan [b], E. Pruyt [c], S.O. Negro [d], M.P. Hekkert [d]

[a] AT Osborne B.V., Postbus 168, 3740 AD Baarn, The Netherlands
[b] Delft University of Technology, Faculty of Technology, Policy and Management, Department of Policy, Organisation, Law and Gaming, Delft, The Netherlands
[c] Delft University of Technology, Faculty of Technology, Policy and Management, Department of Policy Analysis, Delft, The Netherlands
[d] Utrecht University, Copernicus Institute for Sustainable Development and Innovation, Department of Innovation and Environmental Sciences, Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 16 March 2009
Received in revised form 26 August 2009
Accepted 26 October 2009

Keywords:
Perceived uncertainty
Entrepreneurship
Innovation policy
Transitions
Infrastructures
Biomass

ABSTRACT

The transition towards renewable energy production will not occur without the involvement of entrepreneurs who dare to take action amidst uncertainty. In an earlier article, a conceptual model was introduced for analyzing how perceived uncertainties influence the decisions and actions of entrepreneurs involved in innovation projects that aimed at developing and implementing renewable energy technologies. In this article, the conceptual model is applied to stand-alone biomass combustion projects in the Netherlands. Although none of the biomass combustion projects has been abandoned, some entrepreneurs clearly have more difficulty to turn their project into a success than others. To create insight into the underlying dynamics of these projects, the article analyzes what types of positive or negative interaction patterns occur over time between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action and how these patterns can be stimulated or prevented. The results provide several lessons to take into account when designing policies for stimulating the development and implementation of biomass combustion.

1. Introduction

Previous studies on the transformation of the energy system have demonstrated that the success of renewable 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 [1–5]. Within this social system, also called Technological Innovation System (TIS) [6], several actors contribute to the development, diffusion and implementation of a new technology. Whereas previous studies have investigated the dynamics of such a TIS [2–5], this article focuses on one group of actors that plays a prime role in these innovation systems: 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 [5]. 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 the technology), new entrants as well as incumbent companies [5,7,8]. Through their actions, these different types of entrepreneurs help to turn the outcomes of basic R&D activities into commercial technological products to be implemented on a large scale. Thus, the actions of entrepreneurs to a large extent determine whether or not renewable energy technologies are successfully developed and implemented. In order to achieve a transition to a low-emission energy infrastructure as many as possible renewable energy technologies need to be diffused and implemented. The infrastructure for the production,

* Corresponding author. Tel.: +31 35 543 43 43; fax: +31 35 543 43 44.
E-mail address: ime@atosborne.nl (I.S.M. Meijer).

0040-1625/$ – see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.techfore.2010.03.015

transportation and distribution of energy represents an important socio-technical sub-system, implying institutional and socio-cultural changes as well as changes in lifestyle [9]. In this paper we will mainly focus on the first part of the energy infrastructure, i.e. the production of renewable electricity by biomass combustion technology. Therefore, stimulating the breakthrough of renewable energy technologies that contribute to a low-emission energy infrastructure, requires a thorough understanding of the underlying mechanisms that influence entrepreneurial action.

In a previous article [1], perceived uncertainty was introduced as a key component influencing the decisions and actions of entrepreneurs. 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*" [10] (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'. Following McMullen and Shepherd (2006), the argument was made that entrepreneurs will only decide to act if their motivation outweighs the uncertainties he or she expects to encounter. These uncertainties stem from different sources. Uncertainty will not only arise about the technology itself, but also about governmental policy, the availability of resources and the behavior of consumers, competitors and suppliers. Furthermore, it was argued that the decision whether or not to act is constantly reassessed as time goes by. In a case study on the development of biomass gasification projects in the Netherlands, the article illustrated how identifying the dominant sources of uncertainty and analyzing how the balance between perceived uncertainty and motivation changes over time can help us understand why some entrepreneurs decide to stop their activities whereas others continue. The empirical results showed that many entrepreneurial projects were abandoned due to an accumulation of perceived uncertainties and loss of motivation. Negative interactions between different sources of perceived uncertainty and factors in the internal and external project environment (such as changes in the constitution of actors involved, institutional change or external technological developments) appeared to play a crucial role in this.

Building upon the insights of the previous article [1], the aim of this article is to deepen our understanding of how perceived uncertainties influence entrepreneurial action. More specifically, this article focuses on the identification of different types of interaction patterns, as this is still a relatively unexplored topic in the literature on uncertainty and entrepreneurial action. The empirical section of this article consists of a case study on stand-alone biomass combustion plants for combined generation of heat and power (CHP) in the Netherlands. Biomass combustion is considered to be an appealing solution in terms of the overall goal of achieving a transition to a low-emission energy production, as it is a relatively simple technology to convert biomass into electricity and heat. 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 these other technologies [11–13] and that most of the current infrastructure can be used without having to undertake major changes. In contrast to the previous case study on biomass gasification [1], in which almost all projects in the Netherlands were abandoned, the biomass combustion projects are still ongoing. This different outcome of entrepreneurial action makes the biomass combustion case particularly interesting for gaining more insight into the emergence of negative as well as positive interaction patterns. The following research questions are posed:

> How do perceived uncertainties influence the decisions and actions of entrepreneurs involved in biomass combustion projects in the Netherlands?What types of interaction patterns can be identified between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action?

In the next section the theoretical framework on uncertainties will be described in more detail. Section 3 provides insights in the methodology used. In Section 4, the case description can be found. The interaction patterns that influence entrepreneurial action are identified in Section 5. Section 6 concludes by answering the above-mentioned research questions and by providing recommendations on how to accelerate the transition to low-emission energy infrastructure.

2. Uncertainty and entrepreneurial action

As argued in the Introduction, 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 [5]. Because action takes place over time, and because the future is unknowable, action is inherently uncertain [20] (p. 132). Additional to this uncertainty is the innovation component of entrepreneurial action [14–18]. Whether entrepreneurial action concerns the development and exploitation of new products or processes, the creation of new markets, or the establishment of new ventures, it typically involves 'doing something new' [7,19,20]. Therefore, uncertainty is generally considered to be a key component influencing the decisions and actions of entrepreneurs.

In a recent article in the Academy of Management Review, Jeffrey McMullen and Dean Shepherd [20] 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 [20]. Thus, motivation needs to outweigh perceived uncertainty in order for entrepreneurs to act.

In a preceding article [1], several contributions were made to the work of McMullen and Shepherd [20]. 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 [21], it is important to identify which uncertainty sources play a key role and how these

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

Uncertainty source	Description
Technological uncertainty	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	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	Uncertainty about the behavior of (potential or actual) competitors and the effects of this behavior.
Supplier uncertainty	Uncertainty about the actions of suppliers (i.e. uncertainty about the reliability of the supplier), whether 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' 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.
Political uncertainty	Uncertainty about governmental behavior, regimes, and policies, ambiguity in interpretation of current policy or a lack of policy and unpredictability of governmental behavior.

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 [17,22,23]. 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 [22,24]. In addition, the current regulation is aligned with established technologies and does not always provide room for the introduction of new technologies [2]. This creates uncertainty about which institutional regulations and support mechanisms will emerge for the new technology [7]. 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 [1,21,25,26], the following set of uncertainty sources is proposed: technological, resource, competitive, supplier, consumer and political uncertainty (see Table 1).

The second contribution to the work of McMullen and Shepherd [20] is 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. For a transition to become successful, the emerging technology needs to breakout of the niche level. However, not only niche internal processes are relevant, but also changes at the level of regimes and landscapes are needed to provide 'windows of opportunities' [27]. If there is no interaction and alignment between the different levels, no breakthrough will occur. Therefore, 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. Thus, a conceptual model was elaborated which includes the critical factors in the internal (niche level) and external (regime/landscape) project environment (see left-hand side of Fig. 1).[1]

Third, a more dynamic perspective was added. Since the article of McMullen and Shepherd [20] 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. To acknowledge that entrepreneurs constantly reassess their decision to take action in the development and implementation of an emerging technology, we therefore proposed to apply a dynamic analysis of the influence of uncertainty on entrepreneurial action [1]. 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 Fig. 1). This argument was confirmed by the empirical results of a case study on biomass gasification projects in the Netherlands. Although the motivation of an entrepreneur may initially outweigh the perceived uncertainties, the case results showed that the balance between motivation and perceived uncertainties can tip as the project evolves. Interactions between different sources of uncertainty and internal and external factors were found to play a crucial role in this.

Building upon the insights of the previous article [1], this article aims to deepen our understanding of how perceived uncertainties influence entrepreneurial action by focusing on the identification of different types of interaction patterns. In the literature on uncertainty and entrepreneurial action, interaction patterns have not received much attention. This is a shortcoming, since a better understanding of how interaction patterns emerge may provide important lessons for stimulating entrepreneurial action in the transition to low-emission energy systems. Due to the large amount of variables in the conceptual model (different sources of uncertainty, various internal or external factors, motivation, entrepreneurial action), many different types of

[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 (see Fig. 1).

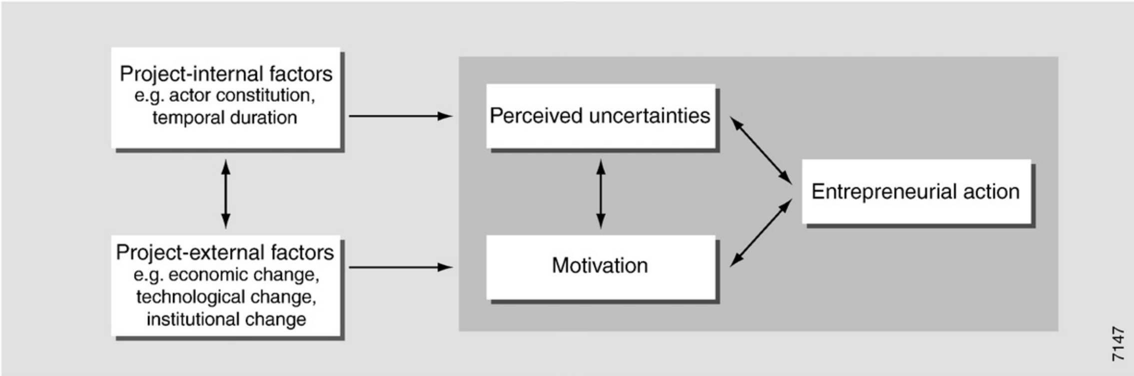

Fig. 1. Conceptual model relating entrepreneurial action to perceived uncertainties, motivation and various internal and external factors.

interactions are possible. These interactions may either have a negative or a positive impact on the balance between perceived uncertainties and motivation. In other words, positive interaction patterns lead to a reduction of perceived uncertainties and/or an increase of motivation, whereas negative interaction patterns result in an increase of perceived uncertainties and/or a reduction of motivation. Identifying different types of interaction patterns may therefore be an important first step in understanding how negative interaction patterns may be prevented and positive interaction patterns could be stimulated.

3. Methodology

The case study focuses on stand-alone biomass combustion installations for combined generation of heat and power (CHP) in the Netherlands[2]. The case study was performed in the autumn of 2006. The set of projects included in this case study consists of ten stand-alone biomass combustion projects that started before 2006 (see Fig. 2). The project selection procedure aimed to include both ongoing and terminated projects. However, only a few biomass combustion projects have been terminated, and these projects were all abandoned soon after their start (i.e. directly after the performance of a feasibility study) [28]. As these projects were of such a short duration, the actors involved had difficulty recalling these projects. Therefore, these projects were excluded from the analysis. The remaining set of projects consists of an equal number of large-scale projects of 15–30 MW_e (e.g. Cuijk, Hengelo, Moerdijk, Alkmaar, 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 at using poultry manure.

Data for this case study was collected by conducting twelve interviews with the entrepreneurs who initiated the biomass combustion projects (mostly energy companies, wood or waste processing companies and farmers) and by studying various types of documents (policy documents, scientific articles, project reports, professional journals and newspaper articles). 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 (see Section 4). To analyze what types of interaction patterns occur, these 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 (see Section 5).

4. Project dynamics

This section describes how the biomass combustion projects evolved over time. Specific attention is given to changes in perceived uncertainties, motivation, internal and external factors and actor behavior. Section 4.1 describes the projects that have reached the exploitation stage, Section 4.2 describes the projects that were at the moment of the interviews (autumn 2006) in the implementation stage, and Section 4.3 describes the project that is still in the start-up stage (see Fig. 2)[3]. Due to word constraints, it was impossible to include chronological descriptions of all the projects. Therefore, some projects are discussed in more length than others. A more detailed description of the projects is reported in [29].

[2] Co-combustion plants and combustion plants for heat production alone (i.e. no electricity production) are excluded from this case study.
[3] The interviews took place in the autumn of 2006. In April 2007, the plant in Moerdijk received a positive verdict concerning the revision license. In 2008, the projects in Hengelo, Alkmaar and Moerdijk managed to complete the implementation stage. The project in Apeldoorn has still not reached the implementation stage.

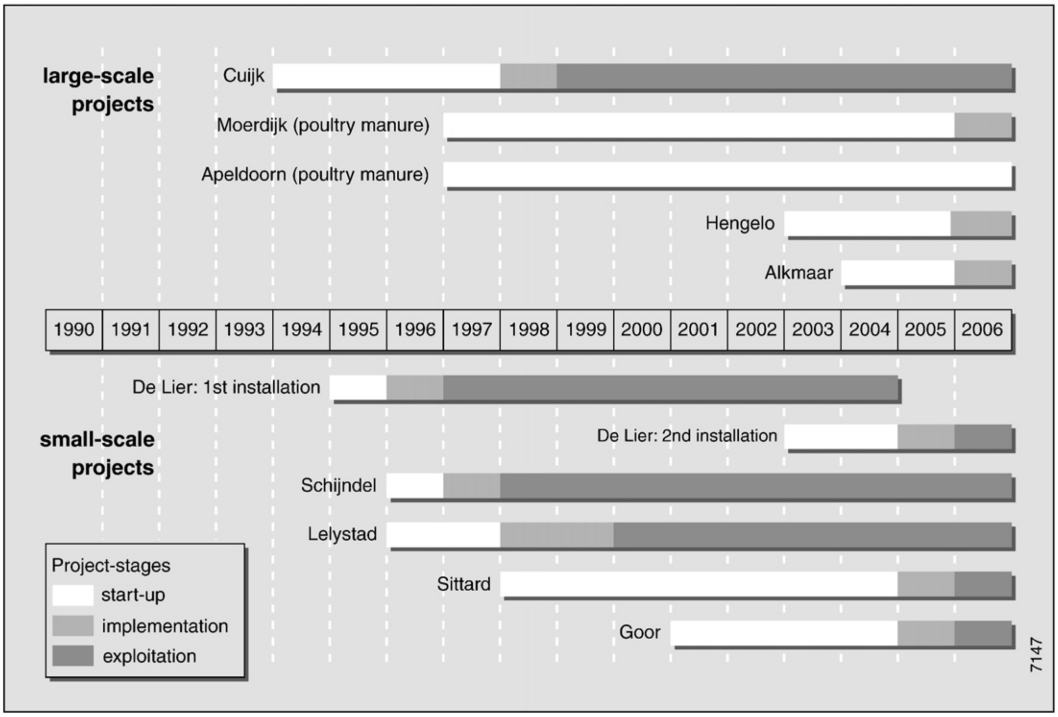

Fig. 2. Timeline of stand-alone biomass combustion projects in the Netherlands.

4.1. Exploitation stage

4.1.1. De Lier

The project in De Lier started in 1995 by timber company De Lange. The project was a follow-up of experiments with biomass combustion for heating of greenhouses. For De Lange, combustion of wood was an opportunity to exploit a stream of residue products that would otherwise be expensive to dispose. A feasibility study showed that a CHP installation with a thermal capacity of 3 MW_{th} (sufficient to provide heat to three greenhouses) was the best option. The entrepreneur was very motivated to undertake this project, out of enthusiasm about the opportunities that biomass combustion technology had to offer, i.e. convert waste into a sustainable product such as low-emission electricity, with hopefully some financial gain.

In the start-up stage and the implementation stage, the entrepreneur perceived little uncertainties. Things changed drastically in the exploitation stage, which started in 1997. When the installation was put into use, several technical problems arose. The oven melted before the necessary temperature was reached, thereby leading to poor combustion conditions and by this to insufficient electricity production and excessive emissions. The technology supplier was unable to solve the problems. As a result, both technological uncertainty and supplier uncertainty increased. To make things worse, the technology supplier went bankrupt. As the entrepreneur was left with a poor-functioning installation and no expertise, perceived uncertainty about the knowledge to continue the project (a form of resource uncertainty) increased as well. Thus, the technical problems and the changes in the actor constitution (withdrawal of the technology supplier) resulted in an accumulation of perceived uncertainties and a delay of the project. The entrepreneur tried to solve the technical problems by consulting several technology suppliers and making various adjustments to the installation. These attempts were unsuccessful. The installation never reached the designed electricity output and was unable to comply with the emission rules [30,31].

In 2003, the local authorities who were responsible for the environmental regulation no longer tolerated the situation and compelled De Lange to stop the biomass combustion activities or to continue with a new installation. De Lange chose for the latter. Despite the technological setbacks of the project itself, De Lange had noticed that other wood combustion projects were operating successfully. These positive external technological developments seemed to counteract the entrepreneurs' own bad experiences [30,32].

Having learned from prior experiences, the entrepreneur became more aware of the various sources of uncertainty and tried to minimize perceived uncertainties as much as possible. A detailed specification of the technical requirements and a more careful selection of technology suppliers aimed to prevent the problems experienced previously. However, to save money, the entrepreneur decided to reuse the steam turbine of the old installation. In January 2006, the new installation was operational. Again, the installation did not reach the designed electricity production capacity. The origin of these problems was found to be in the turbine. At the moment of the interviews, the installation was still not functioning optimally, but by way of 'learning-by-doing' progress was being made [30,32].

In this project, both negative and positive interaction patterns can be identified. Technical problems and changes in the actor constitution negatively influenced the perceived uncertainties (increase of technological and resource uncertainty). An important explanation for the continuation of the project lies in the high motivation of the entrepreneur, which was positively reinforced by successful external technological developments.

4.1.2. Schijndel

The project in Schijndel was initiated by timber company HIS in order to efficiently use the company's wood surplus. This project shows some remarkable similarities to the project in De Lier. In both projects, the entrepreneurs initially perceived little uncertainties and were extremely motivated. In retrospect, the entrepreneur in Schijndel acknowledged that this enthusiasm initially made him ignore uncertainties [33]. Similar to the project in De Lier, the project in Schijndel is characterized by a strong increase of perceived uncertainties in the exploitation stage. When construction of the plant was finished, technical problems arose. These problems led to an increase of technological uncertainty and uncertainty about the availability of knowledge (a form of resource uncertainty). The experimenting activities that were initiated to reduce these uncertainties were unsuccessful. The uncertainties remained and the project was delayed. Because of this delay, the costs were running high and uncertainty about the mobilization of financial resources increased. Due to the rapidly expanding demand for waste wood, uncertainty about the availability and price of biomass resources also increased over time. Despite the increased level of uncertainty, the entrepreneur decided to continue. Feelings of 'entrapment' (i.e. believing that there is no other option than to continue investing in order to regain prior investments) and positive external factors (favorable institutional change and successful technological developments) were found to have a strong influence on this decision.

4.1.3. Cuijk

The first large-scale (25 MW_e) biomass combustion plant implemented in the Netherlands is located in Cuijk. The initial plans arose in 1994. Driven by governmental policies to reduce CO_2-emissions, energy company PNEM (later succeeded by Essent) became interested in the production of electricity from biomass. An engineering firm was hired to perform a feasibility study in which several biomass conversion technologies were compared and the main uncertainties were identified. Combustion technology turned out to be the best option, since technological uncertainties were perceived lower compared to other technologies like gasification. The availability of biomass resources did not form a threat due to the cooperation with the largest national biomass supplier. An elaborate selection procedure helped to keep uncertainty about the reliability of technology suppliers to a minimum [11,34].

Before making the final investment decision, political uncertainty (i.e. uncertainty about the outcome of the license and subsidy application) needed to be reduced. Due to the high costs of constructing a heat infrastructure, the initial idea to supply heat to a nearby paper-mill and a residential area was not very appealing to PNEM. However, the alternative to discard the heat met resistance from environmental organizations and governmental authorities. Due to this resistance, uncertainty about the outcome of the license and subsidy application increased. To gain support for the project, PNEM organized several communication events to discuss this issue with their opponents. This strategy was effective to reduce political uncertainty, since PNEM managed to cancel the supply of heat without endangering the subsidy grant or the license application [34].

Construction of the plant started in 1998 and finished a year later. At the start of the exploitation stage, several technical problems occurred. The problems were caused by the quality of the biomass, which contained too much sand and too much moisture. A stricter selection of the biomass streams and several adjustments to the plant quickly solved these problems. Because the technical problems were regarded to be normal 'teething problems', perceived technological uncertainty remained low. Since then, no other problems occurred. However, Essent stated that the continuation of this project is threatened by perceived uncertainty about the increasing price of biomass (resource uncertainty) and about future financial support of the government (political uncertainty). The company announced to abandon the project if the cost price for biomass exceeds the selling price for renewable electricity. Since the subsidy for the electricity produced by this plant ends in 2009, it remains to be seen what happens to the project after this period [34].

In contrast to the projects in Schijndel and De Lier, this project was not hindered by negative interactions. The entrepreneur of this project had a more profit-oriented (as opposed to enthusiasm-based) motivation and was more aware of the various uncertainty sources. From the start of the project, the entrepreneur initiated various activities to reduce perceived uncertainties as much as possible. These activities resulted in a decrease of uncertainties, which, in turn, positively influenced the motivation to continue entrepreneurial activities.

4.1.4. Lelystad

In 1996, energy company Nuon searched for options to use renewable energy in the existing district heating system. The idea arose to build a small-scale biomass combustion plant to produce heat out of locally-available biomass (wood residues from local forests and parks). The entrepreneur was well aware of the various uncertainty sources and initiated several activities (i.e. technological and market studies, cooperation agreements with biomass suppliers and technology suppliers, etc.) 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 that was initiated to reduce 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 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, which resulted both directly (via cost overrun) and indirectly (via institutional change: the liberalization of the energy market had resulted in stricter investment criteria and a shift of focus towards large-scale projects) in an increase of uncertainty about the mobilization of financial resources. Thus, the change in actor constitution had triggered the emergence of a negative interaction pattern of accumulating uncertainties. To make things worse, the experimenting activities that aimed at reducing uncertainty about the mobilization of financial resources resulted in an increase of technological uncertainty instead. Luckily, the experimenting activities eventually became successful in reducing the perceived uncertainties and thereby the negative interaction pattern was stopped.

4.1.5. Sittard

The project in Sittard was initiated in 1998 by Mrs. Aarts, manager of a gardening business. Mrs. Aarts was hired by the municipality of Sittard to examine the availability and use of local biomass streams. At the time energy company Essent was constructing a district heating system for a new residential area, and Mrs. Aarts put forward a proposal to install a biomass-fuelled CHP installation for the supply of heat to the residential area. The municipality was very enthusiastic about the proposal, but Essent was more reluctant. Since Mrs. Aarts was convinced of the economic feasibility of the project, she decided to establish a new corporation named BES (Biomass Energy plant Sittard) to develop and implement the installation herself [35].

Before making the final investment decision, several uncertainties needed to be minimized. A strategy to manage technological uncertainty was to keep several options open. The original business plan was based on biomass gasification, since this technology had a higher electrical efficiency compared to other technologies like combustion. However, technological uncertainty was high since gasification was not yet a reliable and proven technology. Therefore, Mrs. Aarts examined several alternatives of various technology suppliers before deciding to opt for a biomass combustion installation that best satisfied the project-specific requirements. Further, since the installation would primarily produce heat (which was not subsidized by the government[4]), uncertainty about the market for heat largely influenced the project's economic feasibility. By signing long-term heat supply contracts with Essent and the owner of a local industrial site, this uncertainty was reduced. Mrs. Aarts also perceived uncertainty about the mobilization of financial resources, as she could not finance the project alone. Banks seemed unwilling to issue a loan without guarantees about the long-term availability and price of biomass. Because the project would use low-quality biomass which was relatively cheap and locally available, Mrs. Aarts herself did not perceive any uncertainty about the availability and price of biomass resources. Still, she had to reduce the banks' perceived uncertainty about biomass resources in order to obtain a loan. By signing long-term contracts with biomass suppliers, she managed to comply with the demand of the banks and thereby to reduce uncertainty about biomass and financial resources [35,36].

Despite the entrepreneur's efforts to reduce uncertainties, the project was far from risk-free. Due to the many changes in the emission regulation and subsidy policy, Mrs. Aarts repeatedly had to adjust her business plans. As a result, political uncertainty was perceived as high. Adding to this uncertainty was the tedious licensing procedure. 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, his objections greatly delayed the licensing procedure [35,37]. Uncertainty about the duration of the procedure formed a serious threat to the project. If the installation was not operational on the 1st of January 2006, the heat supply contracts would no longer be valid. Thus, political uncertainty indirectly influenced consumer uncertainty (uncertainty about the market for heat). 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. Although Mrs. Aarts was officially not allowed to start construction of the plant without the license, she believed that the risk of losing the heat contracts was too high. Therefore, she decided to start the implementation stage while the licensing procedure was still not completed. Fortunately, the objections were rejected and the license was granted.

Construction of the plant finished in time, in January 2006. During the first few months, the installation did not run smoothly due to the relatively large pollution of sand, iron scrap and stones in the low-quality biomass. These problems were quickly solved by adding sieves and magnets to the fuel-inlet, which removed the impurities before the biomass entered the oven. Therefore, perceived technological uncertainty remained low. Unfortunately, in May 2007, a fire burned down almost the entire plant [38,39]. Since the data collection had already finished, this incident was not included in the analysis of this article[5]. Reconstruction is taking place to restart biomass combustion activities.

The Sittard-project provides several interesting findings. First, it shows that the uncertainties that entrepreneurs perceive can be influenced by the uncertainties perceived by third parties (like banks, other investors or environmental organizations). Here, the entrepreneur was unable to reduce the uncertainty she perceived about financial resources without dealing with the uncertainty banks perceived about biomass resources. In this way, uncertainties that are of low importance to the entrepreneur itself can still have an impact on the entrepreneur's decisions and actions. Second, it shows that interactions between different uncertainty sources can sometimes result in a trade-off situation. In this case, the strategy to wait until political uncertainty was reduced would increase consumer uncertainty. Therefore, the entrepreneur had to choose which uncertainty was of more importance. The continuation of the project is to a large extent explained by the strong motivation of the entrepreneur. The entrepreneur was willing to take risks in order for the project to proceed according to schedule.

---

[4] Financial support was only given for the *electricity* produced from biomass (MEP-subsidy).

[5] Although this incident did not result in the termination of the Sittard-project, it can have a considerable, sector-wide impact on the perception of technological uncertainty from this moment onward.

4.1.6. Goor

In 2001, energy company Cogas and organic waste recycling company Bruins & Kwast jointly decided to implement a small-scale CHP plant fuelled by contaminated waste wood ('B-quality' wood). Bruins & Kwast was to deliver the waste wood and use part of the produced heat, whereas Cogas was to sell the electricity to its customers. Financially supported by an investment company (Participatiemaatschappij Oost Nederland), they established a joint venture named 'BioEnergieTwente' [40,41].

This project is mainly characterized by a positive interaction pattern: in reaction to perceived uncertainties (technological, political, resource uncertainty), the entrepreneur initiated several activities, such as performing feasibility studies and lobbying for political support and financial resources, which helped to reduce perceived uncertainties and thereby motivated the entrepreneur to continue entrepreneurial action. Another explanation for the continuation of the project, is that perceived technological uncertainty did not increase despite the technical problems that occurred. The reason for this is that the entrepreneurs considered the problems to be normal 'teething problems'. This was also observed in the Cuijk and Sittard projects.

4.2. Implementation stage

4.2.1. Hengelo

Encouraged by governmental policy which stimulated energy production out of non-reusable waste, waste processing company Twence proposed to implement a stand-alone bio-energy plant on their industrial site. Due to the disappointing results of a preceding biomass gasification project in which Twence took part [1], the original plan to implement a gasification plant was abandoned. Twence instead decided to implement a combustion plant, since biomass combustion was considered a 'proven' technology with less technological uncertainty. To profit from economies of scale, Twence aimed at combusting 140,000 tons of waste wood per year. Because of Twence's experience on the waste market, uncertainty about the availability and price for biomass and about the reliability of biomass suppliers was perceived to be low. Twence did perceive uncertainty about technology suppliers, since it proved difficult to find a reliable supplier who could act as a turnkey contractor. After some delay, Twence managed to contract an experienced German technology supplier [42].

Before proceeding to the implementation stage, political uncertainty still needed to be reduced. The final investment decision was largely dependent on whether or not a MEP-subsidy[6] would be granted. Due to the many changes to the subsidy policy, uncertainty about the subsidy application was high. One of the more recent changes involved the obligation to acquire all necessary licenses before submitting a subsidy application. As a result of this policy change, uncertainty about the subsidy application became intertwined to uncertainty about the licensing procedure. Since objections to the license could seriously delay the licensing procedure, and thereby delay the subsidy application, Twence tried to prevent objections by negotiating with environmental organizations. After Twence agreed to comply with stricter emission rules than governmental policy required, the licensing procedure was completed without any objections. When the MEP-subsidy was granted, the final investment decision was made and construction of the plant started in April 2006 [42].

This project again shows the importance of the time factor on the emergence of negative interaction patterns. Due to institutional change (adjustments to the MEP-tariffs), a negative interaction emerged between uncertainty about the request for MEP-subsidy and uncertainty about the duration and outcome of the licensing procedure. The time factor played an important role in this, since the licensing procedure resulted in a delay while uncertainty about the MEP-subsidy was increased by this delay. The continuation of the project can be explained by the successful activities the entrepreneur initiated to reduce perceived uncertainties.

4.2.2. Alkmaar

The project in Alkmaar was initiated by waste processing company HVC. In terms of interaction patterns, the Alkmaar-project shows resemblance to the Hengelo-project. In both projects, institutional change (adjustments to the MEP-tariffs) created a negative interaction between two types of political uncertainty: uncertainty about the request for MEP-subsidy and uncertainty about the duration and outcome of the licensing procedure. As a result, uncertainty about the MEP-subsidy could not be reduced before the licensing procedure was successfully completed. In both projects, the entrepreneurs reacted to this negative interaction pattern by negotiating with potential opponents so as to accelerate the licensing procedure. The activities that the entrepreneur initiated in the start-up stage helped to reduce the perceived uncertainties to an acceptable level. As a result, the entrepreneur decided to continue with the project by proceeding to the implementation stage [43].

4.2.3. Moerdijk

The manure combustion project in Moerdijk was initiated by a cooperation of Dutch farmers (initially under the name of Mestac, later DEP[7]). Due to the increase in livestock and the strict manure disposal regulation, Dutch farmers were confronted with a manure surplus and high manure disposal costs. Manure combustion was seen as a promising option for decreasing the manure surplus while simultaneously producing renewable electricity, which could be sold on the market [44]. More than 8 years after the start, the project finally managed to enter the implementation stage (see Fig. 1). The negative interaction pattern was triggered by

[6] MEP-subsidy: feed-in tariff regulation where biomass power plants (<50 MW) receive between 6.7–9.7 eurocents per kWh produced electricity [53]. The MEP was introduced in 2003 but every so many years the tariffs were altered. Eventually the MEP was abruptly stopped in 2006.

[7] DEP = Duurzame Energieproductie Pluimveehouderij; Sustainable Energy production Poultry Farming.

the resistance of environmental organizations against manure combustion. This lack of social acceptance gave rise to an increase of political uncertainty (uncertainty about the outcome and duration of the license procedure) and changes in the actor constitution (withdrawal of the energy company that would partly finance the project and sell the electricity produced by the plant to its customers). The changes in the actor constitution, in turn, resulted in an increase of consumer uncertainty (uncertainty about the sale of electricity) and uncertainty about the mobilization of financial resources. A new investment partner was found, but the project was seriously delayed. In the meantime, the institutional setting was changing and political uncertainty further increased. In reaction to this increase of political uncertainty, the final investment decision was postponed and the project was again delayed. Because of the new delay, the investment partner 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 when cooperation with a project partner failed for the third time. The search for new partners delayed the project even further and uncertainties that had been reduced by the entrepreneur earlier on in the project started to increase again. Despite the many attempts of DEP to reduce perceived uncertainties, it proved very difficult to break this negative interaction pattern. An important reason for this was that the external factor that had triggered the emergence of the negative interaction pattern (i.e. external resistance from environmental organizations) continued to exist. Nevertheless, DEP kept believing in the opportunities of manure combustion and remained motivated to go on with the project.

4.3. Start-up stage

4.3.1. Apeldoorn

The only project that is still in the start-up stage is the manure combustion project in Apeldoorn, which started in 1997 (see Fig. 1). The project was initiated by Fibroned, a company interested in producing energy out of biomass. Manure combustion was considered to be an attractive feedstock, due to the large availability in the Netherlands [45]. However, 10 years after the start, the project has still not entered the implementation stage. During this long period, two types of negative interaction patterns have occurred. First, two sources of uncertainty negatively interacted. Similar to the projects in Goor and Sittard, the perceived uncertainties of investors negatively influenced the uncertainty that the entrepreneurs perceived about the mobilization of financial resources. This negative interaction did not have many consequences, since the uncertainties were quickly reduced by convincing the investors with positive experiences from other projects and by the participation of NUON. Nonetheless, a second negative interaction pattern could be identified, which was triggered by the opposition from neighbors and environmental organizations (see manure combustion project in Moerdijk). This opposition resulted in big delays, the withdrawal of a project partner and an accumulation of perceived uncertainties (political, consumer and resource uncertainty). Because the entrepreneur did not manage to gain support from the opponents, this negative interaction pattern continued to exist. Nonetheless, the entrepreneur still continues his activities, as his motivation is based on the strong beliefs about the opportunities of manure combustion.

5. Interaction patterns

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 types of interaction patterns can be identified. This section first describes the negative interaction patterns that were found in the biomass combustion projects. However, as all the biomass combustion projects are still ongoing, these negative interaction patterns have not tipped the balance between perceived uncertainties and motivation in any of the projects. The section therefore continues with several explanations for the continuation of entrepreneurial action (in terms of the emergence of positive interaction patterns and the endurance or the absence of negative interaction patterns).

5.1. Negative interactions between uncertainty sources

First, the project descriptions showed several examples of negative interactions between different sources of perceived uncertainty (see Table 2). In each of these examples, one source of perceived uncertainty directly or indirectly resulted in an increase of another source of perceived uncertainty.

Table 2
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
Technological uncertainty + uncertainty about knowledge resources → experimenting → delay → uncertainty about financial resources + biomass resources	Alkmaar Schijndel

As Table 2 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. It happens regularly that 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 2 also gives several examples of indirect interactions. For instance, in the Lelystad-project, uncertainty about the mobilization of financial resources made the entrepreneur of this project experiment with cheaper biomass resources. These experiments were unsuccessful and resulted in technical problems. Since these problems were unexpected, perceived technological uncertainty increased. Thus, in Lelystad, uncertainty about financial resources indirectly resulted in an increase of technological uncertainty.

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 3).

Table 3 shows that the actor constitution, the institutional setting and the social environment (i.e. social acceptance of the project by environmental organizations and neighbors) are important factors influencing perceived uncertainties in the biomass combustion projects. Furthermore, the examples of Table 3 illustrate that these factors can both directly as well as indirectly (by way of other factors) influence perceived uncertainties. For instance, in the Moerdijk-project, institutional change directly resulted in an increase of perceived uncertainty, whereas social acceptance indirectly (via a change in the actor constitution) influenced perceived uncertainty (see Table 3).

5.3. The importance of time within negative interaction patterns

A final remark with respect to Tables 2 and 3 is that both figures 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 2, one source of uncertainty resulted in a delay, which in turn caused 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 in consumer uncertainty. Similar interaction patterns are found in Schijndel, Hengelo and Alkmaar (see Table 2). The examples of Table 3 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 3). 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.

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 reinforced the motivation of the entrepreneurs to continue their actions.

Table 3
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 [a]
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

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

Table 4
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, neighbors 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 and 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 turnkey technology supplier	Lelystad
		Knowledge acquisition: contracting technological experts	De Lier (1) Lelystad
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.

Table 4 displays the various types of activities that have been initiated with the goal of reducing a specific source of uncertainty.[8] A distinction can be made between five types of activities: studying, experimenting, knowledge acquisitioning,

[8] As Table 4 shows, the entrepreneurs of the biomass combustion projects did not undertake specific activities to deal with uncertainty about competitor actions. The reason for this is that competitive uncertainty was not perceived to be an important source of uncertainty [27].

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). In order 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 cooperation is knowledge-acquisitioning. Whereas the cooperation agreement was 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 at reducing 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 show, studying activities are mostly applied in the start-up stage whereas experimenting activities are mostly applied during the implementation stage.

The various activities displayed in Table 4 played an important role in the continuation of entrepreneurial action. Although occasionally the activities of the entrepreneurs resulted in an increase instead of a reduction of perceived uncertainties (see the above Lelystad example, Table 2), most of the 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 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.

5.5. The positive influence of factors in the project environment

In Section 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 showed 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. The success of 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, favorable institutional change (the introduction of the MEP-subsidy) positively influenced the motivation of the entrepreneur. Whereas Table 3 demonstrates that institutional change often resulted in an increase of perceived uncertainty, this project illustrated that institutional change might as well increase the motivation of entrepreneurs. Thus, factors in the project environment can play an important role in negative as well as in positive interaction patterns.

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 with their projects because perceived uncertainties remain low. An interesting conclusion from the interview results is that most entrepreneurs did not perceive technological uncertainty as an important source of uncertainty [29]. The interviewees explained that they perceived biomass combustion to be a 'proven' technology. This perception was largely influenced by successful biomass combustion projects abroad. However, despite the status of 'proven technology', many entrepreneurs were confronted with technical problems. The reason for this is that each project was still to a certain extent unique. Regardless of the fact that all the technical components were proven, the project descriptions illustrated that the integration of these components into a successful installation was highly-dependent on project-specific characteristics. Due to differences in biomass feedstock (such as differences in the degree of pollution or the moisture content) and differences in the application of the installation (large-scale versus small-scale or electricity versus heat production), it is insufficient to simply duplicate the technical design of a successful biomass combustion plant. Furthermore, knowing that entrepreneurs of projects abroad 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 technical 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, which did not affect their perception of biomass combustion technology as 'proven'. The relatively low importance of technological uncertainty, which was seen in most of the projects, may very well have prevented negative interaction patterns between technological uncertainty and the remaining uncertainty sources from emerging.

6. Conclusion

The aim of this article was to come to a better understanding of the influence of perceived uncertainty on entrepreneurial action in the transition to low-emission energy infrastructure. The biomass combustion data showed that various interactions occur over time between (internal or external) factors in the project environment, perceived uncertainties, motivation and entrepreneurial action. These interactions may either positively or negatively influence the balance between perceived uncertainties and motivation. An interesting conclusion from the empirical data is that most biomass combustion projects were characterized by a combination of both positive and negative interaction patterns. A distinction can be made between two types of negative interaction patterns. First, negative interaction patterns can emerge between different sources of perceived uncertainty, meaning that one source of perceived uncertainty directly or indirectly results in an increase of another source of perceived uncertainty. Second, negative interactions may occur between (internal or external) factors in the project environment and perceived uncertainty. An increase of perceived uncertainties in the biomass combustion projects was often triggered or intensified by external factors such as declining social acceptance (in the case of manure combustion), institutional change (such as unexpected changes to the policy instruments), or internal factors, such as a change in the constitution of actors involved in the project (like the withdrawal of an investment partner or a technology supplier). In both types of negative interaction patterns, the time factor proved to play an important role as delay of a project often directly or indirectly (via changes in the actor constitution or institutional setting) resulted in an increase of perceived uncertainties.

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 were abandoned. An important explanation for this is that the negative interaction patterns were not as dominant as the positive interaction patterns. The empirical data contains 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.

As shown also in previous work [29,46] the identification of the factors that trigger positive and negative interaction patterns provides several opportunities for designing policy instruments to further stimulate the development and implementation of biomass combustion projects. In order to contribute to a low-emission energy infrastructure, policy instruments should aim at stimulating positive interaction patterns, and preventing or removing negative interaction patterns. As the case results showed, knowledge development or diffusion activities (such as studying, experimenting or knowledge-acquisitioning) can help to further reduce perceived uncertainties. In addition, knowing about the success of other biomass combustion projects can encourage entrepreneurs of less-successful projects to continue their efforts. Thus, policy instruments that contribute to knowledge development and diffusion can help to further exploit this positive effect.

One of the ways for the government to help prevent negative interaction patterns, is to reduce perceived political uncertainty. Both this article and previous empirical work in which the same approach was used [1,29] bring forward that political uncertainty is one of the most dominant sources of perceived uncertainty hindering entrepreneurial action with respect to the development and diffusion of sustainable energy technologies. Since the development and implementation of emerging energy technologies require large investments with payback periods of at least 10 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 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 behavior 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 [47,48], this political uncertainty is hindering investments in sustainable energy technologies in the Netherlands. Therefore, in order to achieve a transition towards a low-emission infrastructure, government needs to create such an environment where entrepreneurs can experiment with their new technology, For instance, by reducing uncertainty about the licensing procedure and subsidy of biomass combustion projects, a niche market can be established in which sufficient room is provided for entrepreneurs to learn how best to deal with the various other sources of perceived uncertainty they encounter. If some of these entrepreneurs manage to become successful, this will encourage other entrepreneurs to undertake action. In this way, positive interactions within a niche start to reinforce each other and might influence activities on the regime and landscape level. These interactions might lead to a shift in the regime or landscape level, such as simplified licensing procedures, and enable a breakout of the niche.

Besides the uncertainty about the stability of the governmental policy, entrepreneurial actions in the biomass combustion case were also hindered by uncertainty about the mobilization of resources. To further reduce perceived uncertainties within a niche market, governmental policy should therefore aim at mobilizing sufficient risk capital (e.g. by creating favorable conditions for private investors or by establishing a participation fund in which government and private investors jointly invest in entrepreneurial projects).

Thus, the most important factors that could hamper the diffusion of renewable energy technologies in order to contribute to a low-emission energy infrastructure are political uncertainty, technological uncertainty and resource uncertainty. These are all factors that play a role when the technology is still in a niche market and needs to breakout (see also [49] in this issue). If the uncertainties become too high, no breakout will occur. Therefore by supporting uncertainty-management activities as mentioned above, the sustainable energy technology will mature and gain critical mass. However it is also important that at the same time the external factors on the regime and landscape level (e.g. the institutional settings and the social acceptance of the technology) start to align with the needs of the technology in question, in order for a 'window of opportunity' to occur which will allow the technology to breakout of the niche. This alignment on regime and landscape level is only possible if a systemic approach is taken such as recommended in [49], where the transition path of renewable energy production is legitimized as a whole and competition between transition paths is reduced to a minimum.

This kind of analysis of the development of a single transition pathway is a first step as suggested by [50](this issue) to take more into account the interaction between actors and put less emphasis on only technically sound futures, costs and benefits. Finally, in combination with other pathway typologies and analysis such as in [49–52] (this issue) more insight could be created and could contribute to how transition pathways should be designed and analyzed and which policy tools are necessary and successful for a transition towards a low-emission energy infrastructure.

Acknowledgements

This article is part of the research project 'Managing uncertainties in energy innovations and transition processes', which is financially supported by NWO (Dutch Organization for Scientific Research) and KSI (the Dutch Knowledge network on System Innovations and transitions). The authors would like to thank the interviewees for participating in this research.

References

[1] I.S.M. Meijer, M.P. Hekkert, J.F.M. Koppenjan, The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands, Energy Policy 35 (11) (2007) 5836–5854.
[2] S. Jacobsson, A. Bergek, Transforming the energy sector: the evolution of technological systems in renewable energy technology, Ind. Corp. Change 13 (5) (2004) 815–849.
[3] S. Jacobsson, A. Johnson, The diffusion of renewable energy technology: an analytical framework and key issues for research, Energy Policy 28 (9) (2000) 625–640.
[4] S.O. Negro, M.P. Hekkert, R.E.H.M. Smits, Explaining the failure of the Dutch innovation system for biomass digestion — a functional analysis, Energy Policy 35 (2) (2006) 925–938.
[5] M.P. Hekkert, R.A.A. Suurs, S.O. Negro, S. Kuhlmann, R.E.H.M. Smits, Functions of innovation systems: a new approach for analysing technological change, Technol. Forecast. Soc. Change 74 (4) (2007) 413–432.
[6] B. Carlsson, R. Stankiewicz, On the nature, function and composition of technological systems, J. Evol. Econ. (1) (1991) 93–118.
[7] H. Van De Ven, The development of an infrastructure for entrepreneurship, J. Bus. Venturing 8 (3) (1993) 211–230.
[8] R. Garud, P. Karnøe, Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship, Res. Policy 32 (2) (2003) 277–300.
[9] J. Rotmans, R. Kemp, M. Van Asselt, More evolution than revolution: transition management in public policy, Foresight 3 (1) (2001) 15–31.
[10] F.J. Milliken, Three types of perceived uncertainty about the environment: state, effect, and response uncertainty, Acad. Manag. Rev. (1987) 133–143.
[11] Energie- en Milieuspectrum, *Energiebedrijven zien benutting biomassa verschillend.* Energie- en Milieuspectrum, 1997(9): p. 24–26.
[12] IEA Bioenergy. Website IEA Bioenergy Task 29 'How can biomass be used for energy?' (www.aboutbioenergy.info). 2006 [cited 2006 22 June].
[13] BTG. Website Biomass Technology Group (www.btgworld.com). 2005 [cited 2005 27 oktober].
[14] R.R. Nelson, S.G. Winter, In search of useful theory of innovation, Res. Policy 6 (1) (1977) 36–76.
[15] G. Dosi, Technological paradigms and technological trajectories, Res. Policy 11 (1982) 147–162.
[16] C. Edquist (Ed.), Systems of Innovation; Technologies, Institutions and Organizations, Science, Technology and the International Political Economy Series, Pinter, London, 1997, 432 blz.
[17] N. Rosenberg, Uncertainty and technological change, in: R. Landau, T. Taylor, G. Wright (Eds.), The Mosaic of Economic Growth, Stanford University Press, Stanford, 1996.
[18] R.E.H.M. Smits, S. Kuhlmann, The rise of systemic instruments in innovation policy, The International Journal of Foresight and Innovation Policy, 2004, pp. 4–32.
[19] W.B. Gartner, What are we talking about when we talk about entrepreneurship? J. Bus. Venturing 5 (1) (1990) 15–28.
[20] J.S. McMullen, D.A. Shepherd, Entrepreneurial action and the role of uncertainty in the theory of the entrepreneur, Acad. Manag. Rev. 31 (1) (2006) 132–152.
[21] I.S.M. Meijer, M.P. Hekkert, J.F.M. Koppenjan, How perceived uncertainties influence transitions; the case of micro-CHP in the Netherlands, Technol. Forecast. Soc. Change 74 (4) (2007) 519–537.
[22] M.L. Tushman, L. Rosenkopf, Organizational determinants of technological-change — toward a sociology of technological evolution, Res. Organ. Behav. 14 (1992) 311–347.
[23] P. Anderson, M.L. Tushman, Organizational environments and industry exit: the effects of uncertainty, munificence and complexity, Ind. Corp. Change 10 (3) (2001) 675–710.
[24] A.N. Afuah, J.M. Utterback, Responding to structural industry changes: a technological evolution perspective, Ind. Corp. Change 6 (1) (1997) 183–202.
[25] I.S.M. Meijer, M.P. Hekkert, J. Faber, R.E.H.M. Smits, Perceived uncertainties regarding socio-technological transformations: towards a framework, Int. J. Foresight Innov. Policy 2 (2) (2006).
[26] I.S.M. Meijer, M.P. Hekkert, Managing uncertainties in the transition towards sustainability: the cases of emerging energy technologies in the Netherlands, J. Environ. Policy Plann. 9 (3–4) (2007) 281–298.
[27] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Policy 31 (8–9) (2002) 1257–1274.
[28] Green Balance, Evaluatie gestopte kleinschalige bio-energie projecten, SenterNovem, Utrecht, 2004.
[29] I.S.M. Meijer, Uncertainty and Entrepreneurial Action — The Role of Uncertainty in the Development of Emerging Energy Technologies, Innovation Studies Group, University Utrecht, Utrecht, 2008.
[30] Gelderblom, J., *Interview with Mr Gelderblom (Agro Adviesburo)*. 2006: De Lier.
[31] SenterNovem, *Voorbeeldproject bio-energie; De Lier — houtverbranding*. 2004: Utrecht.
[32] De Lange, H., *Personal communication*. 2007.
[33] Van Roy, P., *Interview with Mr Van Roy (Houtindustrie Schijndel)*. 2006: Schijndel.
[34] Remmers, R., *Interview with Mr Remmers (Essent)*. 2006: Den Bosch.
[35] Aarts, M., *Interview with Mrs Aarts (Biomassa Energiecentrale Sittard)*. 2006: Sittard.
[36] SenterNovem, Een Biomassa Energiecentrale voor Sittard, SenterNovem, 2006 Utrecht.
[37] P. De Laat, B. Verhagen, Inzameling biomassa; Een inventarisatie naar gemeentelijke en regionale projecten op basis van regionaal ingezamelde biomassa, SenterNovem, Utrecht, 2005.
[38] M. Vermaas, Materiaalfout oorzaak brand biomassacentrale, , October 10 2007 Agrarisch Dagblad.
[39] AD, Energiecentrale van Sittard door brand volledig verwoest, , May 11 2007 Algemeen Dagblad.
[40] H. Kwast, Interview, , 2006.
[41] Van Hutten, R., *Interview with Mr Van Rutten (Cogas)*. 2006: Almelo.
[42] Rooijakkers, J. and G. Dijkman, *Interview with Mr Rooijakkers and Mr Dijkman (Twence)*. 2006: Hengelo.
[43] Van Lieshout, W., *Interview with Mr Van Lieshout (HVC Alkmaar)*. 2006: Amersfoort.

[44] Munsters, C., *Interview with Mr Munsters (Coöperatie DEP)*. 2006: Tilburg.
[45] Hermans, W., *Interview with Mr Hermans (Fibroned)*. 2006: Utrecht.
[46] S.O. Negro, M.P. Hekkert, R.E.H.M. Smits, Stimulating renewable energy technologies by innovation policy, Sci. Public Policy 35 (6) (2008).
[47] Algemene Energieraad, Energietechnologie voor de toekomst; leren en stimuleren, Algemene Energieraad, Den Haag, 2007.
[48] Company & Bain, Innovation in Sustainable Energy in The Netherlands; Availability of capital and required government support, Bain & Company, Amterdam, 2006.
[49] J. Farla, F. Alkemade, R.A.A. Suurs, Analysis of barriers in the transition toward sustainable mobility in the Netherlands Technological Forecasting & Social Change, (Special Issue 'Transition and Infrastructure') 77 (2010) 1260–1269 (this issue).
[50] T.J. Foxon, G.P. Hammond, P.J. Pearson, Developing transition pathways for a low carbon electricity system in the UK Technological Forecasting & Social Change, this issue (Special Issue 'Transition and Infrastructure').
[51] G.P.J. Verbong, F.W. Geels, Exploring sustainability transitions in the electricity sector with socio-technical pathways Technological Forecasting & Social Change, this issue (Special Issue "Infrastructures and Transition").
[52] F.J. Huetink, A. van der Vooren, F. Alkemade, Initial infrastructure development strategies for the transition to sustainable mobility Technological Forecasting & Social Change, this issue (Special Issue 'Transition and Infrastructures').
[53] A. Faaij, M. Juenginger, IEA Bioenergy task 40 - Country report for the Netherlands, 2005

Dr. Ineke Meijer currently works as a consultant at the management and consultancy firm AT Osborne. Her work focuses on innovation, sustainability and uncertainty management of complex infrastructural projects. Previously, she worked as a researcher at the TU Delft and Utrecht University. She wrote a PhD thesis on uncertainty and entrepreneurial action in the development of emerging energy technologies.

Dr. Joop Koppenjan is an associate professor of public management at the Faculty Technology, Policy and Management of the Delft University of Technology. He studies public policy making and uncertainties in policy networks in the field of infrastructure based public service sectors.

Dr. Erik Pruyt is an assistant professor of Policy Analysis and System Dynamics at the Faculty of Technology, Policy and Management of Delft University of Technology. His methodological research focuses on system dynamics, multicriteria decision analysis, and exploratory modeling and analysis. His applied research mainly focuses on transitions of energy systems, and dealing with acute and/or slumbering crises.

Dr. Simona Negro is an assistant professor at the section Innovation Studies of Utrecht University. She wrote her PhD thesis (2007) on "Dynamics of Technological Innovation Systems — The case of Biomass Energy" and is now conducting her current research on eco-innovation, eco-entrepreneurship and the transition to a sustainable energy system.

Professor Dr. Marko Hekkert is a full professor of 'Innovation System Dynamics' at the section Innovation Studies, a research director of the department of Innovation and Environmental Sciences at Utrecht University, and one of the scientific directors of the Copernicus Institute. Much of his research time is devoted to studying the process of sustainable technological change and eco-innovation.