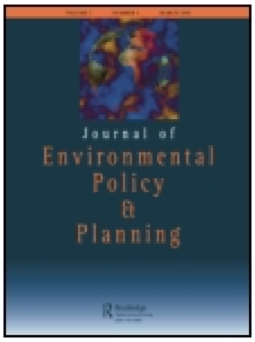

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Managing Uncertainties in the Transition Towards Sustainability: Cases of Emerging Energy Technologies in the Netherlands

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ABSTRACT *Steering technological innovation towards sustainability is a fundamental part of governance for sustainable development. This article uses the term transition to indicate that sustainable technology development not only involves technological changes, but also changes in social and cultural dimensions. The direction and speed of transitions are determined largely by the collective innovation decisions of various actors involved. This article focuses on uncertainties from an actor-perspective, since the uncertainties perceived by the actors involved will influence their decisions greatly. Special attention is given to the entrepreneurs: business firms involved in developing and implementing technological innovation. By examining two empirical cases of emerging sustainable energy technologies in the Netherlands (micro-CHP and biofuels), we demonstrate which types of perceived uncertainties influence the innovation decisions of the actors involved and how these actors respond to perceived uncertainties. Uncertainty about government policy was dominant in both cases. Comparison of both case studies shows that uncertainties have a greater negative effect on innovation decisions when the time-to-market is smaller.*

KEY WORDS: Perceived uncertainty, technological innovation, transition management, sustainable energy technology

Introduction

This article focuses on a particular aspect of sustainable development, namely sustainable technology development. The relation between technology and sustainability is complex and paradoxical (Grubler, 1998). Apart from the advantage of creating economic growth and societal benefits, current use of technologies may cause severe environmental problems, such as pollution and depletion of

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resources. However, technologies may also lead to a more efficient use of resources, less stress on the environment, and cleaning of the environment. Thus, steering technological change towards sustainability—also referred to as "sustainable technology development" (Weaver *et al.*, 2000)—is a fundamental part of governance for sustainable development.

This article does not refer to technology development in the narrow sense, but to the development of technology in interaction with the socio-institutional system in which the technology is embedded (Hekkert *et al.*, 2006). Creating technological change aimed at sustainable development does not only involve technological change but also changes in the social and cultural dimension, such as user practices, regulation and industrial networks (Elzen & Wieczorek, 2005; Geels, 2002b) (see also Grunwald (2007), an article in this special issue). The increasing recognition among scientists and policy makers of this system level of change has led to a rapid diffusion of concepts such as transitions or industrial or socio-technological transformation (Elzen & Wieczorek, 2005; Elzen *et al.*, 2004; Geels, 2002b; Sagar & Holdren, 2002; Smith *et al.*, 2005). A transition, as referred to in this article, is defined as a major, long-term socio-technological change in the way societal functions (such as the supply of energy) are being fulfilled (Geels, 2002b). This long-term transformation at the level of society as a whole, in turn, consists of a sequence of short-term innovations (Geels, 2002b).

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

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

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

Uncertainty and Transition

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

Sources of Perceived Uncertainty

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

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

This article classifies perceived uncertainties according to each of their sources. The source of uncertainty is the domain of the (organizational) environment which the decision maker is uncertain about (Milliken, 1987). Distinguishing different sources is important for choosing appropriate strategies to cope with the uncertainty (Wernerfelt & Karnani, 1987). Based on an extensive literature review, reported in Meijer *et al.* (2006), the following set of uncertainty sources are proposed with respect to innovation decisions of entrepreneurs.

(i) *Technological uncertainty*. This source includes uncertainty about the characteristics of the new technology (such as costs or performance), uncertainty about the relation between the new technology and the infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed) and uncertainty about the possibility of choosing alternative (future) technological options. Uncertainty about the direction of the transition process is reflected in this source of uncertainty.

(ii) *Resource uncertainty.* This source includes both uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation, and uncertainty about how to organize the innovation process (e.g. in-house or external R&D, technology transfer, education of personnel). Resource uncertainty resides both at the level of the individual firm, as well as at the level of the innovation system.

(iii) *Competitive uncertainty.* Whereas technological uncertainty includes uncertainty about competing technological options, competitive uncertainty relates to uncertainty about the behavior of (potential or actual) competitors and the effects of this behavior.

(iv) *Supplier uncertainty.* Uncertainty about the actions of suppliers amounts to uncertainty about timing, quality and price of the delivery. Supplier uncertainty becomes increasingly important when the dependence on a supplier is high.

(v) *Consumer uncertainty.* Uncertainty about consumers relates to uncertainty about consumers' preferences with respect to the new technology, uncertainty about the compatibility of the new technology with consumers' characteristics,[2] and, in general, uncertainty about the long-term development of the demand over time.

(vi) *Political uncertainty.* Political uncertainty comprises uncertainty about governmental behavior, 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 behavior. This source of uncertainty also reflects uncertainties related to the direction of transition processes. More specifically it relates to the uncertainty with which transition directions are backed by government actions and support.

Functioning of Innovation Systems

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

Although each technological trajectory is unique with respect to the technological and institutional setting that influence the transformation process (the so-called 'innovation system'),[3] recent innovation scholars have formulated a generic list of key activities that are essential for achieving a transition. Since these key activities have the function of contributing to the goal of the innovation system, which is the generation, diffusion and utilization of innovations, the term 'functions of innovation systems' (in short 'system functions') is used to describe the set of key activities[4] (Foxon *et al.*, 2005; Hekkert *et al.*, 2006; Huang & Wu, 2007; Jacobsson & Bergek, 2004; Johnson, 2001; Smith *et al.*, 2005). The following system functions are distinguished (Hekkert *et al.*, 2006):

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

According to this functional approach to innovation system policy, stimulating transitions implies stimulating the fulfillment of the aforementioned functions (Hekkert *et al.*, 2006; Jacobsson, 2005; Jacobsson & Bergek, 2004). Following Jacobsson & Bergek (2004), added to this is the fact that uncertainties can be an underlying force with a major influence on the functional pattern of innovation systems. Jacobsson & Bergek (2004) argued that high uncertainty in terms of technology, consumers and changing policy has blocked system fulfillment in the transition to renewable energy technologies. This would imply that policy aimed at stimulating transitions towards sustainability should also focus on the management of uncertainties to promote the fulfillment of system functions. In other words, if perceived uncertainties block the fulfillment of system functions, reducing the size of uncertainties or helping actors to cope with uncertainties may very well be a (indirect) way to stimulate desired functional patterns. The following empirical cases aim to shed light on this issue by analyzing which types of uncertainties are perceived by the actors and how they respond to these uncertainties in terms of the fulfillment of system functions.

The Case of Micro-CHP

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

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

Perceived Uncertainties

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

Technological uncertainty. Since micro-CHP is not yet a ‘proven technology’, the most important element of technological uncertainty was uncertainty about the technology itself (uncertainty about the future performance of the micro-CHP systems in terms of reliability, investment costs, energy efficiency and so on). This uncertainty was perceived to be equally important by all the actors. Uncertainty about the relation between micro-CHP and the technological infrastructure and uncertainty about alternative (future) technological options were perceived as less important. Most of the interviewees did not foresee major technological difficulties connecting micro-CHP to the electricity grid. Nevertheless, as described below, the connection to the grid does lead to substantial political uncertainties. The interviewees indicated that they did not perceive uncertainty about the choice between different technological options, since they keep several options open or believe that each technology can occupy its own niche market.

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

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

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

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

Uncertainties in relation to system functions. Whether or not the perceived uncertainties have hindered the fulfillment of system functions depended on the type of actor in the micro-CHP case. Below, the reactions of the two main market parties are compared: the technology developers versus the potential adopters. Subsequently, the various initiatives of the Dutch government to reduce the uncertainties perceived by the market parties are discussed.

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

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

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

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

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

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

The Case of Biofuels

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

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

Uncertainty about the General Support of Biofuels (1990–95)

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

Initially, these experiments did not lead to a general take-off of the transition to biofuels. Further expansion of activities was slowed down severely by the high prices of biofuels (Rotterdams Dagblad, 2004) and by the unwillingness of the Dutch government to compensate for these higher prices (*ANP*, 1993). In the Netherlands a fierce debate took place on the desirability of biofuels. Environmental organizations and academics questioned the environmental performance of biofuels from sugar beets and canola (first-generation biofuels). On the one hand, EU guidelines forced the Dutch government to stimulate the use of biofuels but, at the same time, the government was also confronted with a lobby against the present production methods of biofuels. This created a climate in which there was a lack of clear policy regarding biofuels. Since government support of biofuels was necessary to compensate for the higher production costs, this led to a poor entrepreneurial climate. A tax reduction on biofuels would lead to competing prices with conventional fuels but, at this point in time, a general tax exemption was not political reality (*ANP*, 1993). The hope for better circumstances remained, due to increasing pressure by the EU on member states to implement policies stimulating biofuels.

Uncertainties about the future of biofuels in the Netherlands led to an agricultural lobby in support of biofuels (*Trouw*, 1995). The agricultural sector was interested in biofuel production, since farmers could collect EU subsidies for producing non-food crops, and they could generate additional turnover by selling feedstock for biofuel production. Eventually, this led to tax exemptions for some biodiesel experiments (*Het Financieele Dagblad*, 1995). These experiments were quite successful and triggered more activities in terms of lobby actions (*ANP*, 1997; *NRC Handelsblad*, 1999), research (*ANP*, 1996; *De Volkskrant*, 1998; *Trouw*, 1995) and coalition forming (functions (vii), (ii) and (iii) in the section 'Functioning of Innovation Systems'). The lobby proved to be successful when regulations for experiments with tax-free biodiesel for trucks passed parliament (*Trouw*, 2001).

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

Uncertainty about the Direction of the Transition Process (1995–2002)

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

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

Uncertainty about Market Formation (2002–05)

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

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

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

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

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

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

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

Conclusions

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

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

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

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

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

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

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

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

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

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

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Notes

1. Non-commercial adoptors are not considered entrepreneurs.
2. For example, an important consumers' characteristic for energy technologies is the energy demand.
3. The concept of 'innovation system' is a heuristic attempt developed to analyze all such societal subsystems, actors and institutions contributing, in one way or another, directly or indirectly, intentionally or not, to the emergence or production of innovation (Hekkert *et al.*, 2006).
4. The term 'key activities' is used when referring to the actor-level and the term 'functions' when referring to the system-level. If a function is being fulfilled well, this means that actors have developed many key activities that contribute to this function. To illustrate, attending a conference or organizing a workshop are examples of actors' key activities, that contribute to the function of 'knowledge diffusion though networks'.
5. All four technology developers that were, at the time, developing activities in the Netherlands were interviewed.
6. The group of potential adopters consisted of organizations that can play an important role in generating intermediary demand for micro-CHP (i.e. energy companies and housing organizations). It was not possible to interview end-users (house owners or tenants), as they have not been involved in the development activities and have not yet been made aware of micro-CHP.
7. Most of the uncertainties that the interviewees mentioned (without having knowledge of our typology of uncertainty sources in this stage of the interview) related to technology or politics. When the interviewees had to rank the uncertainty sources according to their relative importance, technological uncertainty and political uncertainty scored overall highest, followed by consumer uncertainty. Four interviewees clarified their ranking by stressing that technological uncertainty and political uncertainty were far more important in this early stage of development than the other uncertainty sources.
8. Whereas the regular energy policy is aimed at short-term goals (approx. ten years from now), the energy transition policy focuses on the long term. The energy transition policy is based on a different, more process-orientated, governance approach. Some key elements of the 'energy transition policy' involve heterogeneous actors, stimulating learning processes, and creating a wide playing field. For a comparison between the two approaches, see Rotmans (2003).
9. The alternative focus is a direct result of differences in research strategy. Contrary to the CHP case, the biofuels case was analysed according to functions of innovation systems method, as reported in Suurs & Hekkert (2005). Due to these differences in data collection methodology, we are unable to order the importance of the different uncertainties. However, the data allow us to analyse the effect of different uncertainties on entrepreneurial action. The emphasis is on political uncertainties due to a bias in data availability.
10. In the research program that led to this article, additional case studies are being performed on uncertainty perception in technological trajectories around biomass gasification and biomass combustion.

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