Managing uncertainties in the transition towards sustainability: the cases of emerging energy technologies in the Netherlands

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Abstract

Transitions towards sustainability can be considered as long-term transformations at the level of society as a whole, which in turn consists of a sequence of short-term innovations. The direction and speed of transitions are largely determined by the collective innovation decisions of various actors. A crucial characteristic of transitions is that they involve many uncertainties. Not only each of the short-term innovations is surrounded by uncertainties, but also the final outcome of the transition is highly uncertain. There are several, sometimes opposing, visions about the goal of the transition, and these visions constantly change.

The uncertainties that the involved actors perceive is likely to greatly influence their innovation decisions. While different actors each have their own perceptions of uncertainties, objectives, and resources, they will also apply different strategies to cope with perceived uncertainties. Namely, perceived uncertainties might stimulate some actors to fulfill certain key activities that are essential for achieving a transition, while blocking other actors from undertaking these activities. If we want to understand and steer transitions towards sustainability, insight into 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 role of uncertainties in transitions by examining two empirical cases of emerging energy technologies in the Netherlands, namely micro-CHP and bio-fuels. The main question of this article is: Do perceived uncertainties induce or block transition activities in the case of these emerging energy technologies and how do steering initiatives of the Dutch government influence these uncertainties?

The micro-CHP case demonstrates that different types of perceived uncertainties influence the innovation decisions of the involved actors. 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 indeed vary largely between different actors (technology-developers versus potential adopters of micro-CHP). The role of the Dutch government has been quite limited in this early phase of technological development. Despite the large uncertainties about governmental policy and the limited governmental initiatives to reduce these uncertainties, the transition process was not hampered.
The bio-fuels case shows that governmental actions have caused many uncertainties that are difficult to cope with for the involved actors. This has led to many initiatives directed at the Dutch government to reduce these uncertainties. In the case description, we show that this led to new and improved policy directions. Furthermore we demonstrate that, depending on the type of bio-fuel, actors reacted different to the perceived uncertainties. Some actors started investing in new production facilities while others postponed investment decisions. Also we illustrate the role of the EU in the perception of local uncertainties.

Keywords: perceived uncertainty, transition, sustainability, innovation, governance, micro-CHP, bio-fuels.

1 Introduction

Awareness has risen among scholars and policy makers that fundamental changes are necessary in energy supply, transport, agriculture, and many other sectors in order to reach a sustainable future (Rotmans 2003; Van Lente, Smits et al. 2003). The terms 'transitions', 'socio-technological transformation' and 'system innovations' have been used to describe these fundamental transformation processes. A transition, as we will call it in this article, is defined as a major, long-term technological change in the way societal functions (such as the supply of energy) are fulfilled (Geels and Kemp 2000; Geels 2002a). This long-term transformation at the level of society as a whole, in turn consists of a sequence of short-term innovations (Geels 2002a; Geels 2002b). Transitions take at least one generation and involve mutually reinforcing developments in different domains of society, such as economy, technology and politics (Rotmans, Kemp et al. 2001).

Several authors have argued that transitions are difficult to achieve (e.g. (Arthur 1988; Kemp and Soete 1992; Freeman and Perez 1998; Grubler, Nakicenovic et al. 1999; Jacobsson and Johnson 2000; Unruh 2000; Geels 2002a)). A crucial characteristic of transitions is that they involve many uncertainties. These uncertainties play a key role since they are considered to be one of the major blocking mechanisms of transitions (Kemp, Schot et al. 1998; Jacobsson and Johnson 2000; Rotmans 2003). First, the direction and speed of transitions are highly uncertain due to the large number of possible options. There are several visions about the final objective of the transition, and these visions constantly change during the transformation process to adapt to new situations (Rotmans, Kemp et al. 2001). This results in an infinite number of possible future outcomes. In addition, several paths (or 'technological trajectories') are possible to reach each of these outcomes. In turn, each technological trajectory can be composed of several configurations of more or less radical[1] short-term innovations, namely the innovation decisions[2] of individual actors (also called 'transition steps') (Suurs, Hekkert et al. 2004). Second, each of the individual innovation decisions is itself surrounded by uncertainties (e.g. (Nelson and Winter 1977; Dosi 1982; Freeman, Clark et al. 1982; Edquist 1997; Smits and Kuhlmann 2004)). The uncertainties that the involved actors perceive greatly influence their decisions and behavior. Since the behavior of individual actors collectively determines the speed and direction of transition, these perceived uncertainties are likely to influence the transition as a whole.

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[1] Although transitions as a whole can be characterized as radical, the short-term innovations that collectively constitute the transition do not all have to be radical.
[2] These innovation decisions comprise both decisions to develop and to adopt innovations.

Transitions involve a wide diversity of actors. While different actors each have their own perceptions of uncertainties, objectives, and resources, they will also apply different strategies to cope with perceived uncertainties. One of the standard responses to perceived uncertainties is to delay or even to abandon (innovation) decisions (Koppenjan and Klijn 2004). In other words, perceived uncertainties might prevent actors from participating in transition steps. Participating in transition steps in this respect means that actors fulfill certain key activities that are essential for the success of the transition. For example, perceived uncertainties might prevent actors from investing in experiments. Since the final outcome of a transition is uncertain, it is essential for transitions that many of these experiments in various directions take place. Thus, perceived uncertainties can block the fulfillment of key activities and thereby hamper the transition as a whole (Jacobsson and Bergek 2004). However, perceived uncertainties do not necessarily have to hinder transitions. Some scholars argue that organizations in an uncertain environment tend to be more proactive and innovative and tend to assume more risks (Jauch and Kraft 1986). Instead of abandoning or delaying innovation decisions, actors can also accept that innovation is inherently uncertain and consciously deal with these uncertainties. To continue our example, perceived uncertainties can also form a driver for actors to undertake experiments in order to learn about the new technology and thereby reduce uncertainties. Thus, perceived uncertainties might also induce actors to fulfill certain activities that are essential for achieving a transition. If we want to understand and steer transitions towards sustainability, insight into the perceived uncertainties and actors' responses to these uncertainties is a prerequisite.

Although the importance of uncertainty in transition and innovation studies seems widely recognized (e.g. (Nelson and Winter 1977; Dosi 1982; Freeman, Clark et al. 1982; Edquist 1997; Rotmans 2003; Smits and Kuhlmann 2004)), some authors argue that the concept of uncertainty is poorly worked out in innovation studies (Fleming 2001; Corral 2002). The aim of this article is to come to a better understanding of the role of uncertainties in transitions in order to contribute to the difficult task of steering transitions towards sustainability. Ideally, governmental policy should contribute to the management of uncertainties with the purpose of stimulating transitions. However, governmental policy can also be an important source of uncertainty and thereby hamper transitions (Meijer, Hekkert et al. forthcoming), (Meijer, Hekkert et al. submitted). In this article, we hope to demonstrate which types of uncertainties are relevant in transitions towards sustainability and how steering initiatives of the Dutch government influence these uncertainties, by examining two empirical cases of emerging energy technologies in the Netherlands.

The first case is about the development of micro-CHP, an innovative energy conversion technology for domestic application. The second case focuses on the introduction of bio-fuels. Bio-fuels are liquid fuels which are produced from biomass and are used in the transport sector. In the Netherlands, both micro-CHP and bio-fuels are considered as promising options for the transition towards sustainability and many initiatives are currently taking place. The development of micro-CHP and of bio-fuels are therefore interesting cases to study the role of uncertainties in emerging energy technologies. The main question of this article is: **Do perceived uncertainties induce or block transition activities in the case of these emerging energy technologies and how do steering initiatives of the Dutch government influence these uncertainties?**

The methodological approach of this article is outlined in the next section (section 2). In section 3, we describe the theoretical framework on the role of perceived uncertainties with respect to transitions. We then turn to the two empirical cases (section 4 and 5). In conclusion (section 6), we reflect on the types of uncertainties that play a role in transitions and on the way in which steering initiatives of the government can contribute to managing these uncertainties.

2 Methodology

This article consists of a theoretical and an empirical part. As a starting point for studying the role of perceived uncertainties in transitions, we have developed a theoretical framework (described in section 3). This framework was based on a review of uncertainty and innovation literature (see also (Meijer, Hekkert et al. accepted; Meijer, Hekkert et al. submitted)).

The empirical part of this article consists of two cases. In the first empirical case on micro-CHP, we focused on analyzing which types of uncertainties are perceived as important and on how various actors respond to these uncertainties. The data for this case was collected by conducting interviews. We made a distinction between different types of actors, namely technology-developers, potential adopters (i.e. buyers and users of the technology) and the government. We also interviewed an intermediary organization that plays an important role in diffusing knowledge and lobbying for CHP in the Netherlands. We used the typology of uncertainty sources (section 3.1) to classify and rank the perceived uncertainties. The answers about reactions to perceived uncertainties were compared to the list of key activities (section 3.2). In order to reduce the occurrence of strategically correct answers, we tried to verify the interview results by asking interviewees also about the strategies of the other actors (triangulation) and by reviewing grey literature on accounts of the activities of the involved actors.

In the second empirical case, we focused on the influence of governmental policy on perceived uncertainties and transition activities. The data for the second case on bio-fuels was based on a review of grey literature (newspaper articles, professional journals and policy documents), which is reported in (Suurs and Hekkert 2005). The literature study led to a chronological overview of activities that the various involved actors (e.g. governmental institutions, entrepreneurs, environmental organizations) undertook in the Netherlands in the period 1990-2005. From this overview, we analyzed how various steering initiatives of the Dutch government influenced the perceived uncertainties and behavior of the involved actors.

3 Uncertainty and transition

The theoretical framework that we use in this article consists of several parts. In section 3.1, we introduce a typology of perceived uncertainty according to different uncertainty sources. Then (section 3.2), we describe which key activities are essential for achieving transitions and how the fulfilment of these activities relate to perceived uncertainties. Finally (section 3.3), we argue that different actors can have different perceptions of uncertainty and can also react differently to the perceived uncertainty (in terms of whether or not they fulfil the aforementioned key activities).

3.1 Sources of perceived uncertainty

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

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

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

1. **Technological uncertainty:** This uncertainty source includes uncertainty about the characteristics of the new technology (such as costs or performance), uncertainty about the relation between the new technology and the infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed) and uncertainty about the possibility of choosing alternative (future) technological options.
2. **Resource uncertainty:** Resource uncertainty is uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation. Resource uncertainty also includes uncertainty about how to organize the innovation process (e.g. in-house or external R&D, technology-transfer, educating personnel). Resource uncertainty both resides at the level of the individual firm, as well as at the level of the innovation system.
3. **Competitive uncertainty:** Whereas technological uncertainty includes uncertainty about competing technological options, competitive uncertainty relates to uncertainty about the behavior of (potential or actual) competitors and the effects of this behavior.
4. **Supplier uncertainty:** Uncertainty about the actions of suppliers amounts to uncertainty about timing, quality and price of the delivery. Supplier uncertainty becomes increasingly important when the dependence on a supplier is high.
5. **Consumer uncertainty:** Uncertainty about consumers relates to uncertainty about consumers' preferences with respect to the new technology, uncertainty about the compatibility of the new technology with consumers' characteristics[3], and, in general, uncertainty about the long-term development of the demand over time.
6. **Political uncertainty:** Political uncertainty comprises uncertainty about governmental behavior, regimes and policies. Uncertainty can emerge about current policy (e.g. uncertainty about the interpretation or effect of policy, or uncertainty due to a lack of regulation) or about future changes in policy. Uncertainty about governmental

[3] For example, an important consumers' characteristic for energy technologies is the energy demand.

behavior (reliability of the government) is also an important cause for political uncertainty.

3.2 Functioning of innovation systems

In the introduction, we argued that perceived uncertainties can enhance or hinder actors from fulfilling certain key activities that are essential for achieving a 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'[4], recent innovation scholars have formulated a generic list of key activities that contribute to the success of transitions. Since these key activities have the function to contribute to the goal of the innovation system, which is the generation, diffusion and utilization of innovations, the term 'functions of innovation systems' or 'system functions' is used to describe the set of key activities (Johnson 2001), (Hekkert, Suurs et al. submitted), (Jacobsson and Bergek 2004). In this article, we use the term 'key activities' when we refer to the actor-level and the term 'functions' when we refer to the system-level. If a function is being fulfilled well, this means that actors have undertaken many key activities that contribute to this function. To illustrate, attending a conference or organizing a workshop are examples of key activities that an actor can undertake, which contribute to the function 'knowledge diffusion though networks'.
We distinguish the following system functions (Hekkert, Suurs et al. submitted):

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

[4] 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, M. P., R. A. A. Suurs, et al. (submitted). "Functions of Innovation Systems: A new approach for analysing technological change." Technological Forecasting and Social Change.]

contributes to 'learning by interacting' and, in the case of user-producer networks, 'learning by using'. This function is especially important when a heterogeneous set of actors is involved in the innovation process.

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

According to this functional approach to innovation system policy, stimulating transitions implies stimulating the fulfillment of the aforementioned functions (Hekkert, Suurs et al. submitted), (Jacobsson and Bergek 2004), (Jacobsson 2005). We add to this that uncertainties may be an underlying force that has influence on the functional pattern of innovation systems. This implies that policy should also take these uncertainties into account when it aims to stimulate innovation. Reducing the size of uncertainties or helping actors to cope with uncertainties may very well be an (indirect) way to stimulate desired functional patterns.

In order to determine what the relation is between perceived uncertainties and the fulfillment of system functions, we need to take a closer look at the actor-level.

3.3 The actors

Actors have the ability to take action and thereby influence the process of change. Transitions involves a wide variety of actors, who each have their own objectives and play different roles in the transition. Because of these differences, we expect that various types of actors can have different perceptions of uncertainty. In other words, what is certain to one actor, does not have to be certain to another (Huff 1978).

As a results of the differences in objectives, perceptions and roles of the actors, we furthermore expect that the reactions' to perceived uncertainties can differ between the various involved actors. Whereas some actors might react to perceived uncertainties by delaying actions, others will react by undertaking key activities. What's more, distinguishing between the various types of actors helps to explain why some actors are more capable of fulfilling certain key activities than others. For example, intermediary organizations will likely play an important role in knowledge diffusion, whereas technology-developers will likely be better in producing knowledge. Although there is a logical relation between the type of actors and the activities they perform, this is not a simple one-on-one relation. Namely, one actor can contribute to multiple key activities and, likewise, one key activity can be performed by multiple actors.

In short, it is important to identify perceptions of uncertainties and reactions to these uncertainties for the different types of actors in order to understand whether or not perceived uncertainties block the fulfillment of key activities and thereby block the transition as a whole.

4 The case of micro-CHP

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 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.

Micro-CHP can be based on several technologies. The most important competing technologies are the Stirling engine, the gas engine and the fuel cell. The Stirling engine micro-CHP system appears to be the first micro-CHP technology that will enter the Dutch market. The fuel cell system seems to be the most promising technology in the longer term, but is still in an earlier stage of development. The upcoming micro-CHP systems are all fuelled by natural gas and have a connection to the electricity grid. A connection to the grid is necessary, since the forthcoming micro-CHP systems are dimensioned on the heat demand of the household[5]. This means that the installation turns on when the household demands heat. Only then, the installation delivers electricity. Therefore, back-up electricity is needed. Connecting the micro-CHP system to the grid enables the household to import part of its electrical needs from the grid. In addition, the household may also export surplus electricity back to the grid when the heat demand is large and the electricity demand is low.

The utilization of micro-CHP can lead to substantial energy savings and CO_x-emission reduction since the overall efficiency is higher compared to generating space heating, hot water and electricity separately and, because of the decentralized generation of electricity, distribution losses can be avoided. Although micro-CHP is seen as one of the promising technologies for achieving a sustainable energy system, the path towards large-scale application of micro-CHP is still long and there are many uncertainties on the way. Below, we describe the main results of the interviews. In section 4.1 we describe which of the uncertainty sources (section 3.1) the various involved actors perceived. Then (section 4.2), we focus on how the actors reacted to these uncertainties.

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[5] Next generations of micro-CHP systems will likely be dimensioned on the electricity demand. Furthermore, research is taking place to the use of sustainable fuels (biogas or pure hydrogen) instead of natural gas, to increase CO_x-emission reduction of micro-CHP systems even more.

4.1 Perceived uncertainties

According to the interviewees, technological and political uncertainty appeared to be the most dominant uncertainty sources, followed by consumer uncertainty[6]. Below, we describe these three uncertainty sources in more detail. We end this section with a brief discussion on why the remaining uncertainty sources, namely uncertainty about resources, competitors and suppliers, were perceived relatively unimportant.

Technological uncertainty

The most important element of technological uncertainty was uncertainty about the technology itself. This related to uncertainty about the speed of the technological development and the (future) performance of the micro-CHP systems in terms of reliability, investment costs, energy efficiency, and so on. This uncertainty was perceived equally important by all the actors (potential adopters as well as technology-developers) and for all the different micro-CHP technologies (since none of the technologies is yet a 'proven technology').

Uncertainty about the relation between micro-CHP and the technological infrastructure and about alternative (future) technological options were perceived less important. Most of the interviewees did not foresee major technological difficulties connecting micro-CHP to the grid. Nevertheless, as we will describe below, the connection of micro-CHP to the grid does lead to substantial political uncertainties. The interviewees 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.

[6] 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 there ranking by stressing that technological uncertainty and political uncertainty were far more important in this early stage of development than the other uncertainty sources.

Political uncertainty

Many interviewees perceived uncertainty about the reliability of the government in general. This lack of faith is mainly due to unexpected changes in governmental policy, like the sudden ending of many subsidy schemes for renewable energy in the Netherlands, which can be fatal for emerging technologies.

Apart from this general form of political uncertainty, the interviewees enumerated some specific policy issues that created uncertainty for the development of micro-CHP, like 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 uncertainty about the energy taxes and electricity feed-in policy, which strongly influences the economic feasibility of micro-CHP. In the current situation, micro-CHP owners pay energy taxes twice: first on the natural gas that they convert to electricity, second on the electricity that they temporarily 'store' on the grid (by feeding electricity in and at another moment retrieving the same quantity of electricity back). Furthermore, it is still uncertain which price micro-CHP owners will receive from the energy companies for the electricity they feed into the grid[7]. Government regulation is necessary to solve this problem. At the moment of the interviews, this issue was still unsolved and proved to be a clear factor of uncertainty.

Consumer uncertainty

With respect to consumer uncertainty, we can see a clear distinction between the different actors. Technology-developers, on the one hand, seemed convinced about the emergence of a market for micro-CHP and believed that is was 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 however striking, is that this technology-developer indicated to focus only on technological and political uncertainty and to simply ignore consumer uncertainty until the micro-CHP system will be ready for market introduction.

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

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 restrained. These actors did perceive uncertainty about the development of a market, like how large and how fast this market will emerge. Two potential-adopters even considered consumer uncertainty as the most important uncertainty source. They both explained that if consumers don't want micro-CHP, this will bring a stop to the entire development process.

The remaining uncertainty sources

Uncertainty about resources, competitors and suppliers only played a modest role in the micro-CHP case. The reasons for the absence of resource uncertainty differed between the various actors. Actors that have a high stake in the development of micro-CHP (like technology-developers) also seemed to be willing to allocate resources and therefore did not perceive uncertainty about the availability of resources[8]. The opposite reasoning holds as well: actors that did not undertake many activities with respect to micro-CHP in this early phase (like potential adopters), did not need many resources. Two potential adopters explained that they only watched the course of events, but were unwilling to invest in micro-CHP as long as it is an unproven technology.

It is very well possible that resource uncertainty will become more important in later phases, when the technology-developers are faced with increasing pressure to make profit and the ones who will adopt micro-CHP technology are faced with high investment costs. Likewise, competitive and supplier uncertainty might increase in future. For instance, one technology-developer explained that in this phase the technology-developers still cooperate in order to jointly accelerate the development process of micro-CHP (e.g. in the micro-CHP working group which is led by the intermediary organization), but that competition and thereby competitive uncertainty will increase when micro-CHP systems enter the market. Supplier uncertainty might also increase as the market introduction draws near, since technology-developers have to increase their production capacity. Two technology-developers were already trying to enter into cooperation agreements with suppliers in order to produce micro-CHP systems on a large-scale level. One of them perceived uncertainty about finding capable partners.

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[8] Only one technology-developer indicated that the availability of resources to continue their activities was a source of uncertainty. However, compared to the other sources of uncertainty, this source was relatively unimportant to the interviewee.

4.2 *Uncertainties in relation to system functions*

Whether or not the perceived uncertainties hindered the fulfillment of key activities, and thereby the functions (section 3.2) was in the micro-CHP case indeed dependent on the type of actor. Below, we compare the reactions of the two main market parties: the technology-developers versus the potential adopters. Thereupon, we discuss the various initiatives of the Dutch government to reduce the uncertainties that the market parties perceive, in order to stimulate the development of micro-CHP.

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, that is technological and political uncertainty. In reaction to uncertainty about the (future) characteristics of the technology, they all performed R&D-activities. These activities seemed successful, since progress has been made in terms of the performance of the micro-CHP systems (such as improvements in efficiency, reliability and life span). The focus of the R&D-activities has been shifting more and more from basic R&D towards making the product ready for market introduction[9]. Thus, perceived technological uncertainty induced these actors to undertake activities that contribute to the function 'knowledge development' (Function 2, see section 3.2).

In reaction to perceived political uncertainty, the technology-developers undertook activities to create legitimacy for micro-CHP. The technology-developers cooperated with each other and with potential adopters in the micro-CHP working group, which is led by the intermediary organization. This working group has been acting as an advocacy coalition which aims to create legitimacy for micro-CHP by jointly lobbying for government support (Function 7). Another example of an activity which aimed at creating legitimacy for micro-CHP, was the demonstration project that one of the technology-developers initiated. The main goal of this project was to demonstrate that micro-CHP systems worked in real-life situations ('proof of principal') and that the first commercial micro-CHP systems would soon

[9] For example, the technology-developers themselves and the micro-CHP working group are trying to involve installation companies and recently (autumn 2005, after the interviews had been conducted), several technology-developers signed cooperation agreements with suppliers.

enter the market[10]. To sum up, perceived uncertainties stimulated technology-developers to undertake certain key activities (i.e. perceived uncertainties induced function-fulfillment).

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

Government

The government has been stimulating the development of micro-CHP under the framework of the 'energy transition policy'. The energy transition policy is a new governance approach, complementary to the regular energy policy, aimed at stimulating and managing the transition towards a sustainable energy system (Rotmans 2003)[11]. To help shape the long-term energy-transition policy, market parties together with the Ministry of Economic Affairs have outlined several routes towards a sustainable energy system. Within the route that focuses on more efficient or sustainable gas applications, much attention is being given to the application of micro-CHP. Recently, the market parties involved in this route have initiated several experiments with micro-CHP systems. The goal of these experiments is to set the transition in motion and to demonstrate the possibilities of micro-CHP. By expressing that micro-CHP is a promising technology and supporting experiments with micro-CHP, the government helps to guide the direction of the search (Function 4). A strong and visible preference of the government for micro-CHP can positively affect the R&D priority setting and thereby reduces uncertainty about the possibility of investing in different technological alternatives (i.e. technological uncertainty).

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

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

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

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

5 The case of bio-fuels

In this section we discuss the role of uncertainties in the transition towards the use of bio-fuels in the transport sector in the Netherlands. The use of bio-fuels is seen as a promising option for the transition towards a sustainable transport sector in the Netherlands. Bio-fuels are in this article defined as liquid fuels which are produced from biomass and are used for transport purposes. For the production of bio-fuels a wide range of biomass sources can be used, such as sugars, rapeseed oils or woody biomass.

A distinction can be made between the first and second generation of bio-fuels. The first generation of bio-fuels is produced with commercially-available technologies for the conversion of sugars and rapeseed oils into bio-fuels. The second generation of bio-fuels involves the conversion of woody biomass into bio-fuels and is produced with technologies which are not yet commercially available. The conversion of woody biomass into a liquid fuel requires advanced chemical processing or advanced enzymatic technology. The advantages of the second generation of bio-fuels is that much higher volumes of bio-fuel can be obtained from one acre of available land and that the carbon emission reductions are much higher (minus 90%) compared to the first generation of bio-fuels (e.g., minus 30%).

We primarily focus on one type of uncertainty that has proven to be quite dominant, namely political uncertainty. We discuss several examples of (a lack of) policy efforts of the Dutch government that led to political uncertainties for the bio-fuel entrepreneurs and we analyze the consequences of these perceived uncertainties in terms of the activities of the various actors (especially entrepreneurs) involved in the transition. Since the perceived political uncertainty changes over time, we analyze three periods that differ in terms of political climate.

5.1 Uncertainty about the general support for bio-fuels (1990 – 1995)

The first initiatives regarding the use of bio-fuels 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 forces for these experiments were the political pressure from the EU to stimulate the use of bio-fuels and the successful developments in Germany and France. The EU contributed to the financing of these experiments [51].

These experiments did initially not lead to a general take-off of the transition to bio-fuels. Further expansion of activities was severely slowed down by the high prices of bio-fuels [53] and by the unwillingness of the Dutch government to compensate for these higher prices [125]. In the Netherlands a fierce debate took place on the desirability of bio-fuels. Environmental organizations and academics questioned the environmental performance of bio-diesel from rapeseed and bio-ethanol from sugar beets (first generation bio-fuels). The Dutch government was faced by EU guidelines to stimulate the use of bio-fuels on the one hand and by a lobby against the present production methods of bio-fuels on the other hand. This created a climate where no clear policy regarding bio-fuels was formulated.

This led to a poor entrepreneurial climate since government support for bio-fuels has been necessary to compensate for the higher production costs. A tax reduction on bio-fuels would lead to competing prices with conventional fuels but at this point in time a general tax exemption was not a political reality [125]. The hope for better circumstances stayed alive due to increasing pressure of the EU on member states to implement policies to stimulate bio-fuels.

Uncertainties about the future of bio-fuels in the Netherlands led to an agricultural lobby for support for bio-fuels [56]. The agricultural sector was interested in bio-fuel production since farmers could collect EU subsidies for producing non-food crops plus make an additional turn-over by selling feedstock for bio-fuel production. This finally led to tax exemptions for a few experiments with bio-diesel [55, 81]. These experiments were quite successful and triggered more activities in terms of lobby actions [71, 73, 83, 86, 63, 64, 64], research [56, 62, 75] and coalition forming (Function 7, 2 and 3, see section 3.2). The lobby proved to be successful since regulations passed the parliament for experiments with tax-free bio-diesel for trucks [126].

Thus, the political climate can in this period be characterized by the situation that some projects received a temporary tax reduction but meanwhile there was a general uncertainty about the potential of tax reduction for new projects and a follow-up of tax reductions when the given permits would end. On the one hand this political uncertainty slowed the take-off towards the use of bio-fuels, 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.

5.2 Uncertainty about the direction of the transition process (1995 – 2002)

The next phase in the transition was characterized by a clear preference of the Dutch government for the so-called second-generation bio-fuels. This preference found it's origin in the strong lobby of academics and environmental NGO's against first-generation bio-fuels. The second-generation bio-fuels are still in the R&D stage and therefore this period was characterized by a significant effort in R&D and the formation of R&D collaborations. This was financed partly by the Dutch government. Here we see that uncertainty about technological feasibility of second-generation technology was countered by a significant research effort. The parties involved were mainly large vested companies with stakes in the oil, alcohol and technology-development business. Only one starter was part of this process, but this was a spin-off of the multinational Royal Dutch Shell. Generally, the parties involved in second-generation bio-fuels have not been involved in first-generation bio-fuels. The only exemption has been Nedalco, who produces alcohol and has an interest in both (first and second-generation) methods to produce bio-ethanol.

For (potential) entrepreneurs involved in the first-generation technology, this new line of governmental policy created large uncertainties since the future role of first-generation bio-fuels was strongly questioned. Compared to the previous period, an alternative solution has been offered. The result was that in this period the progress in first-generation technology-development and adoption stagnated.

5.3 Uncertainty about market formation (2002-2005)

The significant R&D initiatives have led to a 'proof of principle' for several second-generation technologies. The Dutch government has reserved resources for contributing to the construction of a pilot plant. However, none of the market parties have shown interest in constructing such a pilot plant. The main argument used has been the uncertainty about the size of the Dutch market for bio-fuels. Up to this point, the government has never made a serious effort to create a market for bio-fuels by means of a general tax exemption or by setting a standard for a fixed share of bio-fuels in automotive fuels. In this case it seems that the strategy of the Dutch government to invest in R&D instead of investing in a market for bio-fuels is turning out to be unsuccessful. Even though the R&D initiatives have led to a great deal of knowledge development (Function 2, see section 3.2), the final step towards the market has not been taken by the incumbent companies due to market uncertainty.

Meanwhile, activities related to the first generation of bio-fuels have picked up again. A number of factors have influenced this. First, the pressure of the EU on the Dutch government increased to considerable height. Since the technology-development of second-generation bio-fuels proved to be too slow to meet the EU directive, the government decided to fall back on the first generation and allowed first-generation technology to be part of the R&D program. This proved to be a major boost in creating legitimacy for this technology (Function 7). Another factor of importance was the fact that two players became very active in promoting first-generation technology.

The first actor was the company SolarOilSystems that decided to start building a bio-fuel mill based on rapeseed. They managed to create much local support from state authorities and agricultural organizations, managed to successfully lobby for tax exemptions, and successfully built networks with customers to create complete production and consumption chains. Influenced by this example and by the expectation that the EU directive will be implemented in the Netherlands in 2004, seven oil mills are build.

Another active entrepreneur is Nedalco, a Dutch producer of alcohol. Nedalco is involved in the second-generation R&D program to produce ethanol from wood, but simultaneously lobbies for better market conditions for first-generation bio-ethanol based on sugar beets. Nedalco's commercial interest in the production of bio-ethanol is large, due to the potential increase of it's production capacity, leading to lower production costs and higher profits. Nedalco manages to lobby for a temporal tax exemption for a fixed amount of ethanol and some R&D subsidies.

In 2005 the Dutch government decided that it needs to make a serious effort to come up with a long-term vision regarding bio-fuels in the Netherlands. Since the R&D trajectory probed to be too slow, the government switched from R&D stimulation to market stimulation by means of a tax exemption (till 70 million euro) for all bio-fuels in 2006 and an obligation for oil companies to mix 2% bio-fuel in automotive fuels in 2007.

At the moment, it is too early to analyze how these market stimulation instruments will influence the activities of the entrepreneurs. However, Nedalco already stated that this policy does not give them enough certainty to invest in a bio-ethanol plant. A good business case is only possible for them when sufficient contracts are signed with potential customers of bio-ethanol.

This period shows a remarkable difference in the type of actions that entrepreneurs take under similar regimes of political uncertainty. We see that incumbent companies with a small interest in these developments postpone investments since market conditions are uncertain. Nedalco, an incumbent producer with high stakes in these new developments, undertakes significant lobby activities but can not make a good business case under these uncertain market conditions. Finally, we see small entrepreneurs, new entrants that under high market uncertainties still make investments and are very active in influencing their environment. One possible explanation for the difference in behavior is the required capital investments in technology. For Nedalco and the second-generation technologies investments are very steep, while first-generation technology is relatively low-tech resulting in lower investment costs.

6 Conclusion

The aim of this article was to come to a better understanding of the role of uncertainties in transitions, by examining two empirical cases about emerging energy technologies in the Netherlands. We posed the following research question: ***Do perceived uncertainties induce or block transition activities in the case of these new energy technologies and how do steering initiatives of the Dutch government influence these uncertainties?***

The micro-CHP case demonstrates that different types of perceived uncertainties influence the innovation decisions of the involved actors. 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 vary largely between different actors.

Technology-developers actively try to cope with the uncertainties they perceive by undertaking certain key activities that contribute to the functioning of the innovation system. In reaction to technological uncertainty, they undertake knowledge-development activities. In reaction to perceived political uncertainty, the technology-developers undertook 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 undertake some activities, such as participating in demonstration projects that were initiated by technology-developers, but are unwilling to make large investments 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 phase of technological development. Governmental action has not been enough to reduce the political uncertainties that play such a dominant role in the micro-CHP case. Despite the perceived uncertainties and the limited governmental initiatives to reduce these uncertainties, the transition process was not hampered since technology-developers have been taking a leading role and are still making progress in the development of micro-CHP.

Comparing this case to the bio-fuels case leads to some remarkable similarities and differences. First we noticed that also in the bio-fuels case, 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 bio-fuels, while others do invest in production-facilities. The size of the initial investments and the ability of the entrepreneurs to build networks with potential customers seem to be crucial in these decisions. This again acknowledges the often-described principle that small new-entrants are more capable in deploying flexible strategies in fast changing markets than large incumbent firms.

Another similarity is that the high level of political uncertainty in the bio-fuels case did not lead to a lack of key activities. In fact, many lobby activities (which contribute to the system function ‘creation of legitimacy’) and a significant number of research activities (i.e. ‘knowledge development’- function) are observed. However, compared to other countries, the number of entrepreneurial activities in the Netherlands has been very low. It becomes very clear that the large political uncertainties blocked the diffusion of bio-fuels in the Netherlands. Thus here we notice that uncertainties block crucial system functions (e.g., entrepreneurial activities). This is different from the micro-CHP case where we did not find these patterns.

Thus, what we see for bio-fuels is that perceived uncertainties stimulate the actors to undertake certain activities, with the aim of countering these uncertainties (i.e. political uncertainty induces lobby activities in order to reduce these political uncertainties) and that activities take place that are typical for early phases of development (e.g., knowledge development). This is in line with our findings in the micro-CHP case. Micro-CHP is in a very early stage of transition as well, and in this case we also see that activities are deployed to counter specific uncertainties (e.g., knowledge development for countering technological uncertainty and networking and lobbying to counter political uncertainty). When the technology is further developed and is technologically suitable for entering the market, the influence of uncertainties seem to be much larger than in earlier phases of transition. In this case large uncertainties hamper the fulfillment of crucial system functions. A logical explanation for this phenomenon is that when a firm is in the phase of entering a market with a new product, much more resources are needed and more management commitment is necessary than in earlier phases. In this phase a solid business-case needs to back-up investments plans and convince 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.

What are the implications for policy? First, perceived uncertainties play an important role in innovation and transition processes. Second, in very early phases of transition the role of uncertainties seem to be less crucial than in later phases. This gives policy makers time to develop suitable instruments to reduce uncertainties for entrepreneurs or help them to cope with uncertainties. Third, the types of activities taken by entrepreneurs seem to be a good indicator for the types of uncertainties that are hampering further development of the transition process.

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