Technological Forecasting & Social Change 79 (2012) 448–456

Contents lists available at SciVerse ScienceDirect

Technological Forecasting & Social Change

Patterns of expectations for emerging sustainable technologies

Floortje Alkemade [a,*], Roald A.A. Suurs [b]

[a] Utrecht University, Department of Innovation and Environmental Sciences, P.O. Box 80115, 3508TC Utrecht, The Netherlands
[b] Netherlands Organisation for Applied Scientific Research, (TNO), Strategy and Policy, P.O. Box 49, 2600 AA Delft, The Netherlands

ARTICLE INFO

Article history:
Received 6 May 2010
Received in revised form 11 August 2011
Accepted 13 August 2011
Available online 9 September 2011

Keywords:
Expectation dynamics
Sustainable innovation
Hype cycles
Innovation systems
Functions of innovation systems
Biofuels
Hydrogen
Natural gas

ABSTRACT

Innovation is characterized by uncertainties, high risks, large investments and late returns on investment which make it a complex process. This is particularly true for sustainable innovation where market forces alone cannot be relied upon to realize the desired transitions. Insight in the dynamics of such innovation processes is necessary in order to influence technological change toward a more sustainable direction. However, few instruments and indicators are available to assess the performance of emerging technological innovation systems. In this phase competition often takes place based on expectations rather than on technological performance. This paper therefore focuses on the expectation patterns of technological innovation systems in the exploratory phase through the analysis of the expectation dynamics of three emerging technologies in the field of sustainable mobility within the Netherlands: biofuels, hydrogen as a transport fuel and natural gas as a transport fuel. These technologies do not only compete with the current fossil-fuel based system but also with each other. We have collected over 5000 expectation events regarding these technologies for the period 2000–2008 and discuss the insights generated by the comparison of the observed expectation dynamics to theoretical patterns.

1. Introduction

Innovation is characterized by uncertainties, high risks and late returns on investment which make it a complex process. This is particularly true in the case of innovations for sustainability where market forces alone are not sufficient to come to a more sustainable socio-technological regime [1–3]. The large scale diffusion of energy-efficient and more sustainable energy and mobility technologies is necessary to realize such a transition. It is however difficult to predict which technological options have the most potential to become part of a future more sustainable socio-technological regime. The development of sustainable energy- and mobility technologies is characterized by long development times, large required investments and the involvement of many actors. These actors include the entrepreneurial firms that bring new technological options to the market, the government actors that stimulate and support the development and market introduction of innovations through protective measures or public procurement, as well as consumers and NGOs. The speed and direction of technological change thus depend on the nature of the technological (innovation) system [4]: "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology".

In the case of innovations for sustainability, technology generation, diffusion and utilization may be hampered by a "double externality" problem [5]: In addition to R&D related market failures, there also exist positive externalities related to the adoption and diffusion of environmentally friendly technologies (e.g., clean air). Because of these externalities entrepreneurial firms may not be able to appropriate all the benefits of their innovation. Other factors that complicate the diffusion process are the involvement of a heterogeneous set of actors with different preferences and the competition between innovations for

* Corresponding author.
E-mail addresses: f.alkemade@uu.nl (F. Alkemade), roald.suurs@tno.nl (R.A.A. Suurs).

0040-1625
doi:10.1016/j.techfore.2011.08.014

sustainability and other new and existing technologies—both on traditional performance characteristics and on sustainability characteristics [6]. In several countries policies are therefore in place in order to stimulate the emergence and development of technological innovation systems for more sustainable energy and mobility technologies i.e., [7,8]. Expectation based methods such as foresight exercises and scenario studies are an important input for policy makers in this area.

However, few instruments and indicators are available to assess the potential performance of emerging technological innovation systems as performance criteria are still unclear in the early stages of development [9–12]. Therefore competition between alternative technological options often takes place based on the *expectations* about future technological performance rather than on current technological performance [13–17]. Expectations influence the development path of a technology and several authors indicate that expectations are therefore the subject of strategic behavior by entrepreneurs and other stakeholders [18]. Aldrich and Ruef [19] for example stress the importance of legitimisation strategies in addition to technology development (learning) strategies for entrepreneurs. In the early stages of the technology life cycle entrepreneurs create legitimacy for the new technology through the management of expectations and by providing information [20]. These guidance activities are a way for stakeholders to influence the technological innovation system toward a favorable direction. When market driven technological innovations are concerned this behavior has been studied in the context of product preannouncements [21]. However, in the case of sustainable technologies, such as biofuels, the entrepreneurial firm is just one of the actors trying to influence the expectations about a technological option. Other stakeholders within the innovation system such as, for example, the environmental lobby and the government may also attempt to influence the direction of technological change. This complex environment makes the task of expectations management difficult and this paper addresses the need to better understand the expectation patterns for sustainable technologies [22,23].

A theoretical framework that acknowledges the important role of expectations for emerging technologies is the functions of innovation systems approach which describes the basic functions that need to be facilitated in technological innovation systems in order to build up and function well [24,2,25]. Of particular importance in the early stages of development of a new technology is the so-called “guidance of the search function” [26,27]. This function involves activities that provide direction to the development of the emerging technology. Activities that provide this guidance are for example the implementation of policy measures, standard setting, and the expression of promises and expectations regarding technological development and performance. Several case studies using the functions of innovations approach have emphasized the important role of expectations and have described the patterns of expectations observed in these individual cases [28,29]. In this paper we seek to link the expectations identified in case studies of sustainable mobility technologies to the general literature on expectation dynamics [30]. This allows us to investigate whether sustainable innovations show similar expectation patterns and it contributes to a more empirical description of the guidance of the search function in the technological innovation systems literature.

In summary, the influence of expectations on policies for sustainable development, the importance of expectations in emerging innovation systems for sustainable technologies, and the influence of the expectations of multiple heterogeneous actors on technology development raise the need for more insights in the expectation patterns of emerging sustainable technologies. An expectation pattern is the temporal pattern of expressed expectations about a technology. Our focus is on the expression of expectations by actors, by expressing expectations these actors influence the technological innovation system and current and future technological trajectories [9,31].

More specifically, this paper considers three emerging technologies in the field of sustainable mobility within the Netherlands: biofuels, hydrogen and natural gas as fuels for the automotive sector. These three technologies can potentially provide an alternative for the current fossil-fuel based mobility system. There is thus both competition between the incumbent fossil fuel-based technology on the one hand and the three alternative technological options on the other hand and between the three alternative technological options. While it is not necessary the case that this competition results in a single dominant technology (a coexistence of different options may also be possible), these technologies do currently compete for subsidies. Furthermore, all three technologies require substantial investments in infrastructure increasing the chances of lock-in in a single technology [32,33]. The three technologies differ with respect to their stage of development and their compatibility with the current infrastructure. A switch to hydrogen might therefore be considered as a more radical innovation than a switch to biofuels or natural gas as the main transport fuel. However, large scale deployment of each option requires infrastructure investments as well as adaptations to the vehicle and can thus be considered disruptive to the existing fossil-fuel based regime [34].

In order to better understand the role of expectations in these three technological trajectories the paper proceeds as follows: First, Section 2 elaborates on the role of expectations in innovation processes as described in the literature [14,35,23]. Section 3 describes the methodology of event-history analysis [36] that was used to collect data on the expectations about the three technologies during the period 2000–2008. Section 4 gives a short overview of the case study data and presents the observed expectations in the three case studies. Finally a discussion and concluding remarks are given in Section 5.

2. The role of expectations in innovation systems

We follow Borup et al. [22] in describing technological expectations as “real time representations of future technological situations and capabilities”. Expectations play an important role in determining the direction of technological change and the rate at which innovations are adopted [35,22,18,14,37,38]. First, expectations function as a coordination mechanism for actors and activities [39]. Positive expectations help to attract actors to emerging innovation systems and to align the interests and activities of these actors [40]. Second, through these processes of alignment and coordination expectations can also create legitimacy for the new technology [23,19]. Very strong positive expectations can even help create a protective niche around a technology, within such a niche the technology is more likely to be positively evaluated [39,41]. Third, expectations play an important role in mobilizing resources for the new technology. Geels and Smit [18] even indicate that expectations and visions about the future as such are an important resource in the creation of protected niches for the new technology. Finally, (shared) expectations can reduce the uncertainty perceived by technology developers and thereby guide the process of technological change. Expectations thus play a pivotal role in attracting actors to the technological innovation system and to stimulate the fulfillment of other key processes in technological innovation systems such as the mobilization of resources. This role of expectations is strongest in the earliest phases of the life cycle of a technology which is characterized by uncertainty regarding future performance and possible applications [42]. It is this early phase of development that is the focus of this paper.

The importance of expectations for technology development creates incentives for actors to express and influence technological expectations. Several authors have identified such strategic elements in expectation formation processes [18,41,43,19,44]. Berkhout [35] even suggests that expectations can be considered: “as bids about what the future might be like, that are offered by agents in the context of other expectation bids”. This implies that agents make these bids strategically, i.e., with the knowledge that other actors will ‘counter’ and respond with alternative bids. An important strategy for stakeholders at this stage of technological development is to try and improve the reputation of their preferred technology through the management of expectations and by providing information [20,45], this is an example of a *proactive* expectations management strategy. Proactive expectations management strategies have an important role in creating legitimacy for new technologies [19,18]. A more *reactive* form of expectations management occurs when actors react to negative expectations expressed by other actors. Reactive expectations strategies occur, for example, when biofuel stakeholders respond to the critical statements about the (un)sustainability of biofuels. In this paper we consider the pattern of expectations expressed by a certain actor as an expectations management strategy. Expectations can be considered as more successful once they are shared by a larger number of influential stakeholders [46] and the effectiveness of an expectations management strategy depends on several aspects.

First, the content of the expectation is important. Berkhout [35] indicates that the validity and attractiveness of expectations are important in determining which expectations become dominant over time, i.e., become shared by a large number of people. Proponents of a certain technology often make an effort to frame the discussion about competing technologies in such a way that the strengths of their preferred technology become important performance criteria in the process of technology selection [47,48]. An example of this is stressing the potential of a technology on the long term when current performance is not yet competitive. Expectations can be specific, addressing the performance of the new technology, or more general concerning the ability of the innovation to contribute to solving societal problems. An example of a general expectation is “Hydrogen as a freedom fuel” whereas a specific expectation also indicates future technology performance such as “Hydrogen cars will be cost-competitive in 2015”. In addition to the specificity of an expectation one can also distinguish expectations that relate to the short term from those that relate to the long term. Low performance expectations on the short term can sometimes be compensated by high expectations about technology performance on the long term. Furthermore, Expectations can be positive, highlighting the expected benefits of the technology, or negative, expressing for example the potential risk associated with the new technology. It is important to distinguish between these different types of expectations as they can have different effects on innovation processes [43].

Expectations concerning a specific technology are of course influenced by expectations concerning competing (existing and new) technologies. Rosenberg [14] for example states that “Expectations of continued improvement in a new technology may therefore lead to postponement of an innovation, to a slowing down in the rate of its diffusion or to an adoption in a modified form to permit greater future flexibility”. High expectations regarding a new technology may for example lead to an increase in R&D and marketing efforts for the existing technology and cause a sailing ship effect.

Second, in addition to the content, the actor or actor group expressing the expectation influences the impact of the expectation [35]. An important actor group consists of the entrepreneurial firms that are willing to invest in the new technology. These entrepreneurial firms can be both new entrants and incumbents. Other stakeholder groups are for example the incumbent firms that are threatened by the new technology [49], governments that see a role for the new technology in achieving policy goals and stakeholder groups such as NGOs and lobby organizations. Expectations can bring together a particular stakeholder group and the size and power of the group influences the effectiveness of the expectations management strategy used by the (group) members, that is, expectations become stronger when there is alignment between different stakeholder groups. Expectations expressed by some actors (such as the government) potentially have a greater impact on the emerging technological innovation system than expectations from other actors. However for these influential actors the reputational costs that arise when high expectations cannot be fulfilled may negatively influence future credibility and diffusion of the technology [39].

Expectation dynamics often show a typical pattern over time with alternating cycles of hype and disappointment [43,20,50]. A hype cycle occurs when there is a sudden rise in positive expectations regarding a technology followed by a sharp decline in positive expectations or a rise in negative expectations. These ups and downs can have a strong impact on innovation processes [43]. The disappointment that arises when the initial high expectations cannot be met, can lead to large costs for the emerging innovation system in terms of both resources and reputation [20]. As sustainable technologies are often dependent on substantial (public and private) funding, we expect that there is an incentive for stakeholders to overstate the potential of their technologies possibly leading to hype and disappointment cycles. Another pattern described in the literature, refers to the changes in the nature of the expectations of a technology over time. For example high and diffuse initial expectations are replaced by more specific expectations as a technology develops [15]. For example abstract representations of ‘the car of the future’ are replaced by expectations based on actual prototypes [51]. With this progression the distance between the actual performance of the technology and the expectation decreases, thereby reducing the level of uncertainty associated with the technology.

3. Data and methodology

Traditional methods for the analysis of innovation processes such as patents, R&D investments and other firm level data do provide insights in innovation system functioning in more mature stages of development but are less suitable for emerging systems [52]. In this paper we therefore build on the recent functions of innovation systems approach. This approach describes the basic functions that need to be addressed in emerging technological innovation systems in order to build up and function well [2,25]. The performance of a technological innovation system can then be studied by analyzing how these functions are facilitated by the system. This approach recognizes the importance of expectations which are classified as contributing to the *guidance of the search function* of technological innovation systems. This system function describes the process of selection and alignment that is necessary for further system development, involving, for example, policy targets, outcomes of technical or economic studies and expectations regarding technological development and performance.

A systematic, methodology to analyze the realization of system functions is *event history analysis*, as developed in the context of organisation studies [36,53]. Event history analysis studies sequences of events as a way to analyze processes of change and thus offers the possibility of operationalising and measuring system functions by relating these functions to events. Within the context of a technological innovation systems analysis, an event can be defined as an instance of change with respect to actors, institutions and/or technology which is the work of one or more actors and which carries some public importance with respect to the system under investigation. Examples of events that contribute to the guidance of the search function are standard setting, expressions of positive or negative expectations about the technology as well as promises or targets expressed by actors with the power to change institutions. In the event history analysis of the emerging Dutch biofuels innovation system by Suurs [29] empirical support for the importance of the guidance of the search function was given by the fact that over 40% of the events that were collected related to this innovation system were classified as guidance of the search. The current paper focuses on the expectation events within this broader guidance of the search category.

As a source for our event history analysis we used Dutch newspapers and professional journals[1] in the period 2000–2008. We thus focused on those events in which expectations were expressed regarding the use of biofuels, hydrogen and natural gas as transport fuels. This was done by reading through the literature and separating, throughout each text, the events reported. The construction of the event sequences was done as 'objectively' as possible based on empirical sources. To minimise personal bias the identification and classification of events was performed independently by three researchers after which differences in interpretation where discussed and resolved.

This method resulted in a number of 3811 expectation events for biofuels, 989 events for hydrogen as a transport fuel and 943 events for natural gas as a transport fuel. For each case we then constructed a database containing the events in chronological order. Note that all events were counted irrespective of their importance. However, events that provide important guidance to the system are covered in more articles than less important events and are thus more prominent in the database. This is for instance the case with a statement about the hydrogen economy by former US president Bush (Hydrogen as freedom fuel). The resulting database provides an overview of events and the time of their occurrence. Subsequently we determined the following characteristics of each event:

1. Positive/negative content: Does the content of the expectations event express positive or negative future technology performance?
2. General/specific content: Does the event concern general guidance or expectations specific to the technology? Expectations can be specific, addressing performance of the new technology, or more general concerning the ability of the innovation to contribute to solving societal problems.
3. Short term/long term content: Does the expectation relate to the near future (<10 years) or the distant future?
4. Actor type: Entrepreneur, government, knowledge institute, NGO, other.
5. Furthermore, within the biofuels database we also distinguish between first and second generation technology.[2]

While we acknowledge that the content of an expectation plays an important role in determining the guiding capacity of that expectation we focus mainly on the patterns of expectations for each case study in order to enable a comparison between case studies and with the more general literature. For each actor type we now consider the pattern of expectations expressed over time by actors of this type. Not all events can however be attributed to a specific actor type, these events are classified as "other". This category mainly contains editorial comments, articles written by journalists and important events that happened abroad (e.g., technological breakthroughs). While there may be a strategic element to those events as well we have focused on expectations expressed by stakeholders in the Dutch technological innovation systems, that is explicit expectations management events. The events in the "other" category are taken into account when assessing the overall expectations regarding a specific technology.

[1] Using the 'Lexis/Nexis' database we performed a keyword search (in Dutch) for each of the three cases. See [29] for an overview of the literature and the Dutch keywords that were used.

[2] The technological innovation system for biofuels comprises two technology generations. First generation biofuels fuels are based on conventional technologies and use agricultural crops, such as rapeseed or sugar beet, to produce biodiesel or bioethanol. Second generation biofuels originate from more science-based technologies (chemical and biotechnological). With the second generation technologies, woody biomass, consisting of waste wood or cultivated energy crops, is converted to 'biocrude', 'Fischer-Tropsch biodiesel' or 'cellulosic bioethanol' (all synthetic substances). Second generation biofuels are currently in a pre-commercial stage of development.

4. Observed expectation patterns

In addition to the theoretical patterns described in Section 2 this section elaborates on the expectation patterns of the three case studies. Table 1 gives an overview of the number of expectation events that were generated by the different actor groups. Table 1 indicates that entrepreneurial firms play a prominent role in the discourse about the technology for the three technological innovation systems we have investigated. This is consistent with patterns described in the broader literature as described in Section 2. However, we also observe an important role for the government in the biofuels and natural gas technological innovation systems. With regard to content, many of the expectations expressed by the government are related to standards and regulations concerning the use of transport fuels. Below we consider the expectation patterns for each system in more detail.

4.1. Expectation patterns for natural gas as a transport fuel

Fig. 1 presents the expectation patterns for natural gas as a transport fuel during the period 2000–2008. In Fig. 1a we see that the expectations are predominantly positive. In addition, we observe a strong rise in the number of expectations in 2007, followed by a decline in 2008 suggesting hype cycle dynamics. Fig. 1b illustrates that both entrepreneurial firms and the government play a dominant role in this technological innovation system. Also note that the expectations generated by government and entrepreneurs follow a similar pattern. First this may be an indication that expectations are aligned, second it may be an illustration of the fact that expectations are mutually interdependent and that there are feedbacks between the expectations expressed by government and entrepreneurs. That is, actors may strategically react to expectations expressed by other actors rather than act based on the underlying technology developments. This type of strategic behavior contributes to the hype. Fig. 1c shows the percentage of expectations that are 'specific' in relation to the total number of expectations and the percentage of expectations that are about 'the short-term' (<10 years) in relation to the total number of expectations. An example of an event describing a specific expectation about natural gas expressed by construction company Ballast Nedam is:

> Ballast Nedam expresses its intention to invest 75 million euros in the construction of 250 refueling stations for natural gas. "The company fleet of 500 cars will switch to natural gas within the next 5 years." (Financieel Dagblad March 15, 2008—in Dutch).

An example of a more general event contributing to positive expectations:

> "Natural gas is a better alternative than biofuels for achieving clean mobility" (Het Parool, January 30th 2008—in Dutch).

When we consider the level of specificity and the percentage of expectations that consider the short term we observe a converging pattern in Fig. 1, that is, over time expectations become more specific and focus more on the short term. In the beginning of the period there were some years with mostly general expectation whereas towards the end of the period the level of specificity increases and most expectations are about the short term. As described above, the convergence of expectations is an important condition for the emergence and establishment of a dominant design and as such is a precondition for the system to move from the exploratory to the growth phase. This convergence of expectations is thus an indicator of the development of the technological innovation system [54].

4.2. Expectation dynamics for hydrogen

Fig. 2 shows the expectation dynamics for hydrogen as a transport fuel. Fig. 2a again shows a pattern with first a large increase in positive expectations and a subsequent decrease, an indicator for hype cycle dynamics. Fig. 2b illustrates that the entrepreneurial firms play a dominant role in the discourse about hydrogen technology for transport and, as in the case of natural gas, the expectation dynamics for government actors and entrepreneurs are similar. In the case of hydrogen (Fig. 2c) this convergent pattern is not observed. This is an indication that the hydrogen system is not yet ready to move to the next stage of development, the stage of commercialisation (of a dominant design).

Table 1
Number of expectation events (positive or negative) generated by the different actor groups.

	Natural gas	Hydrogen	Biofuels
Entrepreneurial firms	378	421	1403
Knowledge institutes	33	152	676
Government	430	218	1261
NGOs	23	27	139
Other	76	189	332

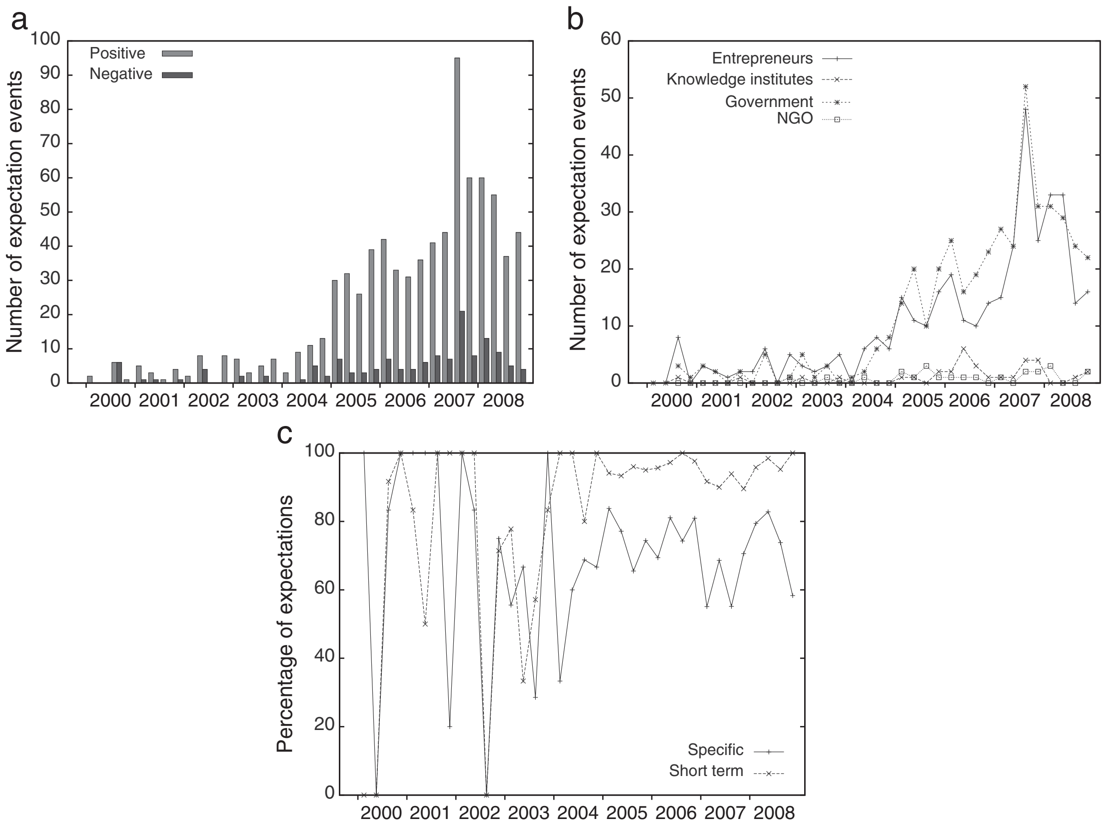

Fig. 1. Expectation patterns for the Natural Gas technological innovation system. a: Positive and negative expectation events per time period, b: events per actor type per time period, and c: specificity/timeframe of expectations.

4.3. Expectation patterns for biofuels

Fig. 3 shows the expectation patterns for biofuels. Fig. 3a shows the expectation patterns for the overall biofuels technological innovation system. Again, characteristics of hype cycle dynamics can be observed. These dynamics do however differ from the observed dynamics for natural gas and hydrogen which showed a strong rise and subsequent decline in positive expectations. In the case of biofuels we see a strong rise in positive expectations followed by a strong rise in negative expectations. This is an indication that expectations are not shared in this case, indicating a lower guiding capacity for the innovation system. As this system consists of two technology generations Fig. 3 shows the dynamics for each generation separately. The graphs for the first (Fig. 3b) and second (Fig. 3c) generation biofuels indicate that this rise in negative expectations can almost completely be contributed to the first generation biofuels. At that time questions arose about the sustainability of this first generation due to its competition with food resources. Second generation biofuels were not associated with this problem, although biofuels remain widely criticized in general. Much of the negative press for biofuels in the period thus finds its roots in the competition between the two technological generations. Adversaries of the first generation of biofuels think the environmental costs of these fuels are too high and they fear that investment in this generation may lead to a lock-in, thereby hindering the diffusion of second generation biofuels. Proponents of the first generation, on the other hand, see the first generation as a stepping stone toward a more sustainable fuel system. With respect to the specificity of expectations shown in Fig. 3d we observe that observations become more general over time. Again this is an indicator that there is no sign of emerging consensus concerning the performance criteria of biofuels technology.

5. Concluding remarks

In this paper we have studied technological innovation systems in the exploratory phase of development by describing the expectation patterns of emerging sustainable technologies. Insight in these expectation patterns was obtained through analyzing the actual patterns of expectations expressed by actors within three case studies of emerging sustainable innovations: biofuels, natural gas and hydrogen. Using the method of event history analysis we have collected data on the expectations about these three technologies during the period 2000–2008. These three technologies are in different stages of development. Hydrogen as a transport fuel and second generation biofuels are currently only tested in small scale pilot projects. First generation biofuels and

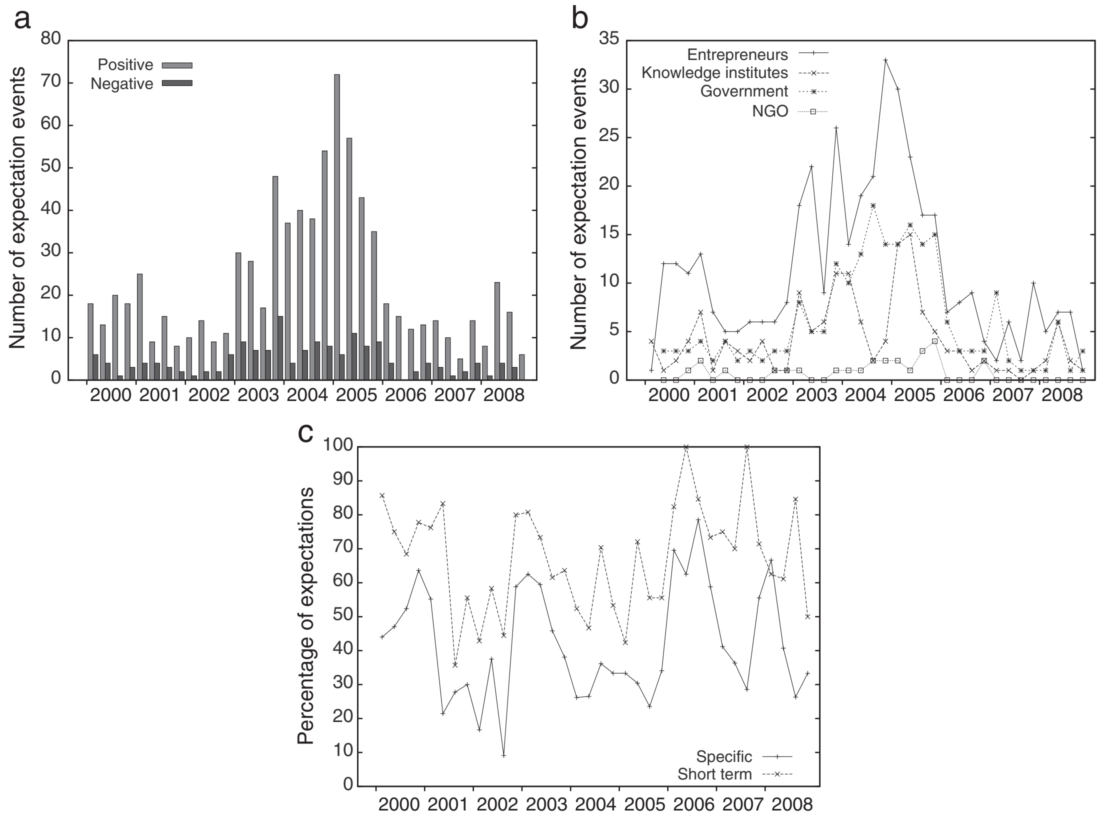

Fig. 2. Expectation patterns for the hydrogen technological innovation system. a: Positive and negative expectation events per time period, b: events per actor type per time period, and c: specificity/timeframe of expectations.

natural gas are commercially available but not yet implemented on a large scale in the Netherlands. With respect to the actors that express expectations we found that both entrepreneurial firms and government actors play a prominent role in the discourse about the investigated technologies. This role of government actors may be specific for sustainable technologies as the government naturally has a role in the development and diffusion of these technologies due to the double externality problem associated with innovations for sustainability.

For all three technologies we found indications of hype cycle dynamics. That is, for all three cases we observed sharp increases in positive expectations followed by either a sharp decrease in positive expectations (natural gas and hydrogen) or a sharp increase in negative expectations (biofuels). While such hype patterns may be beneficial for technology patterns as they assist in mobilizing resources and legitimacy this is not necessarily so as only in the case of natural gas as a transport fuel we see a clear convergence of expectations. We argue that such a convergence of expectations can be used as an indicator for the extent to which expectations are shared. The lack of convergence in the biofuels and hydrogen system is an indication that in these systems there is not yet a broad consensus on the performance criteria for the technology. This lack of consensus can create barriers for further innovation system development. In the case of hydrogen this is consistent with the stage of development of the technology. In the case of first generation biofuels and biofuels in general the decreasing levels of specificity indicate that a reorientation of the system is taking place after the phases of hype and disappointment. Expectation dynamics for emerging sustainable technologies thus follow patterns similar to general expectation dynamics described in the literature. However the patterns observed in these three cases diverge from theory in two important ways. First, we observe an important role for the government. Second we observe that expectations do not always converge even when technologies already have some market share as in the case of biofuels. Several factors can explain the large influence of the government regarding sustainable technologies in the mobility sector. Switching to a new transport fuel involves considerable investment in infrastructure and changes in regulation indicating a role for the government [32]. Furthermore in the early stages of development these technologies are to a large extent dependent on government subsidies as they are not able to compete on price with fossil fuels. This dependence on subsidies might also help explain the second observation that expectations do not always converge. In the case of hydrogen this observation is consistent with the pre-market development phase of the technology. In the case of biofuels however there is already considerable diffusion due to regulations but no consensus yet on the best technological design (wait for second generation biofuels or use the first generation as a stepping stone technology). This lack of consensus may become a barrier for the further development of the biofuels system. Describing patterns of expectations in a systematic way allows us to compare different cases and to identify

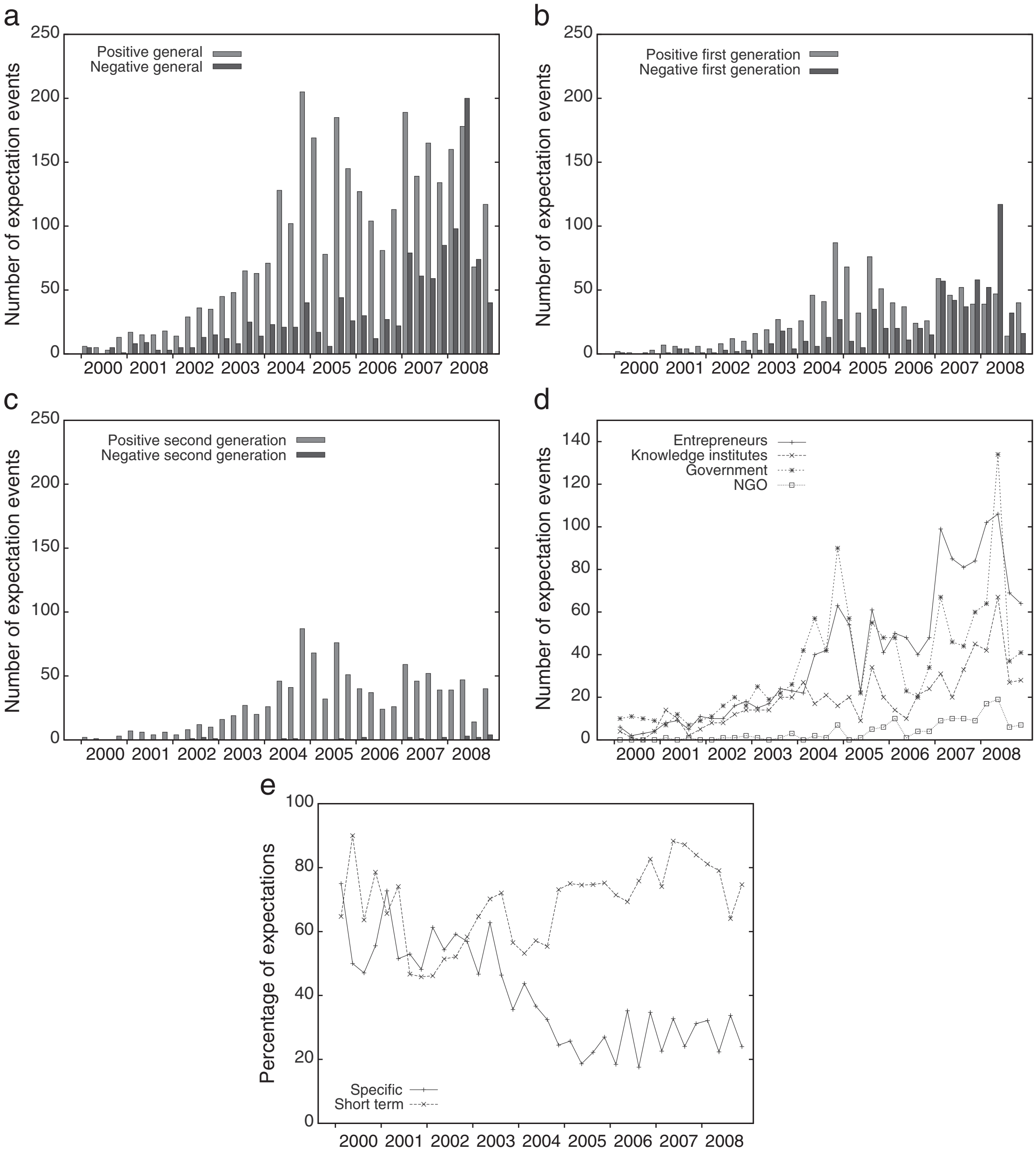

Fig. 3. Expectation dynamics for the biofuels technological innovation system. a: Positive and negative expectation events per time period, b: Positive and negative expectations first generation biofuels. c: Positive and negative expectations second generation biofuels. d: events per actor type per time period, e: specificity/timeframe of expectations.

typical patterns that may be associated with success or failure. The expectation patterns thus provide insights regarding the development of technological innovation systems and provides insights for policymakers especially when considering the implementation of market formation policies for sustainable technologies. More specifically we recommend that policymakers take expectation dynamics into account when basing policy on foresight and scenario studies that depend on technological expectations.

Acknowledgements

The authors thank Wijnand Jonkers and Reinier van der Wees for assisting with the data collection and Harro van Lente and two anonymous reviewers for useful comments and suggestions. Furthermore we gratefully acknowledge the support of NWO (VENI grant 451-08-015).

References

[1] R. Kemp, L. Soete, The greening of technological progress, an evolutionary perspective, Futures 24 (5) (1992) 437–457.
[2] S. Jacobsson, A. Johnson, The diffusion of renewable energy technology: an analytical framework and key issues for research, Energy Policy 28 (9) (2000) 625–640.
[3] K. Rennings, Redefining innovation—eco-innovation research and the contribution from ecological economics, Ecological Economics 32 (2) (2000) 319–332.
[4] B. Carlsson, R. Stankiewicz, On the nature, function and composition of technological systems, Journal of Evolutionary Economics 1 (2) (1991) 93–118.
[5] V. Oltra, Environmental innovation and industrial dynamics: the contributions of evolutionary economics, DIME Working paper No. 7, 2008.
[6] F. Tilley, B. Parrish, Introduction to sustainability entrepreneurship research, Greener Management International 55 (2009) 5–12.
[7] A. Smith, F. Kern, The transition storyline in Dutch environmental policy, Environmental Politics 18 (1) (2009) 78–98.
[8] OECD, Better policies to support eco-innovation, OECD Studies on Environmental Innovation, , 2011.
[9] G. Dosi, Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, Research policy 11 (1982) 147–162.
[10] J. Utterback, Mastering the Dynamics of Innovation, Harvard Business Press, 1996.
[11] F. Alkemade, K. Frenken, M. Hekkert, M. Schwoon, A complex systems methodology to transition management, Journal of Evolutionary Economics 19 (4) (2009) 527–543.
[12] B. Andersson, S. Jacobsson, Monitoring and assessing technology choice: the case of solar cells, Energy Policy 28 (14) (2000) 1037–1049.
[13] S. Klepper, Industry life cycles, Industrial and Corporate Change 6 (1) (1997) 145–182.
[14] N. Rosenberg, On technological expectations, The Economic Journal 86 (1976) 523–535.
[15] N. Rosenberg, Perspectives on Technology, Cambridge University Press, 1976.
[16] H. van Lente, S. Bakker, Competing expectations—the case of hydrogen storage technologies, Technology Analysis and Strategic Management 22 (6) (2010) 693–709.
[17] F. Phillips, Market-oriented Technology Management, Springer Verlag (Berlin), 2001.
[18] F. Geels, W. Smit, Failed technology futures: pitfalls and lessons from a historical survey, Futures 32 (2000) 867–885.
[19] H. Aldrich, M. Ruef, Organizations Evolving, Sage, London, 2006.
[20] H. van Lente, Promising technology: the dynamics of expectations in technological developments. (PhD thesis), Twente University of Technology, 1993
[21] J. Farrell, G. Saloner, Installed base and compatibility: innovation, product preannouncements, and predation, The American Economic Review 76 (5) (1986) 940–955.
[22] M. Borup, N. Brown, K. Konrad, H. van Lente, The sociology of expectations in science and technology, Technology Analysis and Strategic Management 18 (3/4) (2006) 285–298.
[23] N. Brown, M. Michael, A sociology of expectations: retrospecting prospects and prospecting retrospects, Technology Analysis and Strategic Management 15 (1) (2003) 3–18.
[24] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: a scheme of analysis, Research Policy 37 (3) (2008) 407–429.
[25] M. Hekkert, R. Suurs, S. Negro, S. Kuhlmann, R. Smits, Functions of innovation systems: a new approach for analysing technological change, Technological Forecasting and Social Change 74 (2007) 413–432.
[26] K. Hillman, R. Suurs, M. Hekkert, B. Sandèn, Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden, Technology Analysis and Strategic Management 20 (5) (2008) 593–612.
[27] R. Suurs, M. Hekkert, Competition between first and second generation technologies: lessons from the formation of a biofuels innovation system in the Netherlands, Energy 34 (5) (2009) 669–679.
[28] S. Negro, M.P. Hekkert, R. Smits, Stimulating renewable energy technologies by innovation policy, Science and Public Policy 35 (6) (2008) 403–416.
[29] R. Suurs, Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems (Thesis), Innovation Studies Group, Copernicus Institute, Utrecht University, Utrecht, 2009.
[30] K. Eisenhardt, Building theories from case-study research, Academy of Management Review 14 (4) (1989) 532–550.
[31] G. Dosi, R. Nelson, An introduction to evolutionary theories in economics, Journal of Evolutionary Economics 4 (1994) 153–172.
[32] J.A. Gómez-Ibáñez, Regulating Infrastructure: Monopoly, Contracts and Discretion, Harvard University Press, 2003.
[33] J. Farla, F. Alkemade, R. Suurs, Dutch transition toward sustainable mobility: analysis of barriers in the transition toward sustainable mobility in the Netherlands, Technological Forecasting and Social Change 77 (2010) 1260–1269.
[34] R. Adner, D. Levinthal, The emergence of emerging technologies, California Management Review 45 (1) (2002) 50–66.
[35] F. Berkhout, Normative expectations in systems innovation, Technology analysis and strategic management 18 (3/4) (2006) 299–311.
[36] A. Van de Ven, D. Polley, R. Garud, S. Venkataraman, The Innovation Journey, Oxford University Press, New York (NY), 1999.
[37] D. Mercer, General hypothesis of aggregated expectations, Technological Forecasting and Social Change 55 (1997) 145–154.
[38] D. Mercer, Determining aggregated expectations of future outcomes, Technological Forecasting and Social Change 55 (1997) 155–164.
[39] K. Konrad, The social dynamics of expectations: the interaction of collective and actor-specific expectations on electronic commerce and interactive television, Technology Analysis and Strategic Management 18 (3/4) (2006) 429–444.
[40] M. Eames, W. McDowall, M. Hodson, S. Marvin, Negotiating contested visions and place-specific expectations of the hydrogen economy, Technology Analysis and Strategic Management 18 (3/4) (2006) 361–374.
[41] B. Truffer, J.-P. Voß, K. Konrad, Mapping expectations for system transformations: lessons from sustainability foresight in German utility sectors, Technological Forecasting and Social Change 75 (2008) 1360–1372.
[42] P. Anderson, M. Tushman, Technological discontinuities and dominant designs: a cyclical model of technological change, Administrative Science Quarterly 35 (4) (1990) 604–633.
[43] A. Ruef, J. Markard, What happens after a hype? How changing expectations affected innovation activities in the case of stationary fuel cells, Technology Analysis and Strategic Management 22 (3) (2010) 317–338.
[44] G. Kawasaki, Selling the Dream: A Guide to Evangalism, Harper paperbacks, 1992.
[45] Y. Balcer, S. Lippman, Technological expectations and adoption of improved technology, Journal of Economic Theory 34 (2) (1984) 292–318.
[46] B. Budde, M. Weber, F. Alkemade, Expectations and actor strategies in the field of 'green' vehicles, SSRN Working paper.
[47] A. Tversky, D. Kahneman, The framing of decisions and the psychology of choice, Science 211 (4481) (1981) 453–458.
[48] J. Sung, M. Hopkins, Towards a method for evaluating technological expectations: revealing uncertainty in gene silencing technology discourse, Technology Analysis and Strategic Management 18 (3/4) (2006) 345–359.
[49] T. Stenzel, A. Frenzel, Regulating technological change—the strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets, Energy Policy 36 (7) (2008) 2645–2657.
[50] S. Bakker, The car industry and the blow-out of the hydrogen hype, Energy Policy 38 (11) (2010) 6540–6544.
[51] S. Bakker, Hydrogen patent portfolios in the automotive industry—the search for promising storage methods, International Journal of Hydrogen Energy 35 (13) (2010) 6784–6793.
[52] F. Alkemade, M. Hekkert, C. Kleinschmidt, Analysing emerging innovation systems: a functions approach to foresight, International Journal of Foresight and Innovation Policy 3 (2) (2007) 139–168.
[53] M. Poole, A. van de Ven, K. Dooley, M. Holmes, Organizational Change and Innovation Processes, Theories and Methods for Research, Oxford University Press, 2000.
[54] S. Bakker, H. van Lente, M. Meeus, Arenas of expectations for hydrogen technologies, Technological Forecasting and Social Change 78 (2011) 152–162.

Floortje Alkemade is an assistant professor at the Department of Innovation and Environnmental Science at Utrecht University.

Roald Suurs is a researcher at TNO Strategy and Policy.