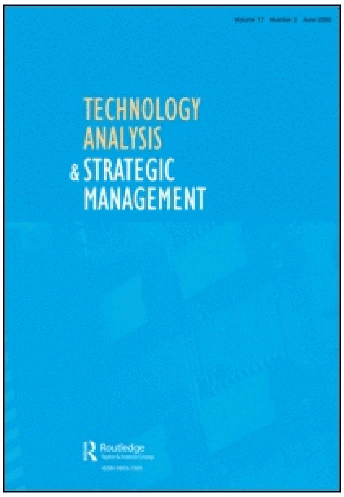

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Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970-2006): hype-cycles, closed networks and technology-focused learning

Geert Verbong [a]; Frank W. Geels [a]; Rob Raven [a]
[a] Eindhoven University of Technology, The Netherlands

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Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970–2006): hype-cycles, closed networks and technology-focused learning

Geert Verbong, Frank W. Geels and Rob Raven*

Eindhoven University of Technology, The Netherlands

This article analyses long-term innovation policies and development trajectories of four renewable energy technologies: wind energy, biomass, fuel cells and hydrogen, and photovoltaics. These trajectories and policies are characterised by many costly failures, setbacks, hype-disappointment cycles, tensions, and struggles. Although setbacks and non-linearities are a normal part of innovation journeys, a comparative analysis of four cases shows the recurrence of particular problems. Using Strategic Niche Management as analytical approach, we conclude that major problems exist with regard to learning processes (too much technology-push, focused on R&D), social networks (supply side oriented, narrow, closed) and expectations (hype-disappointment cycles, limited competence to assess promises).

Keywords: niches; renewable energy technologies; innovation journey; innovation policy; Strategic Niche Management

1. Introduction

Although there is much talk in the Netherlands about energy transitions, implementation of renewable energy is low compared to other European countries (Figure 1).

The low Dutch share of renewable energy is not for lack of effort. Since the 1970s, there have been many policy activities, investments and projects to develop and implement renewable energy options. The Environmental Policy Plan (1989) and the Third Energy White Paper (1995) paid much attention to environmental problems and climate change and formulated high ambitions (e.g. 10% renewable energy in 2020). But there has been a large gap between policy goals and the implementation of substantive policy measures to reach those goals (Verbong and Geels 2007). There have been many costly failures, setbacks, hype–disappointment cycles, tensions, and struggles in innovation journeys with renewable energy innovations. This is

*Corresponding author. Email: F.W.Geels@tm.tue.nl

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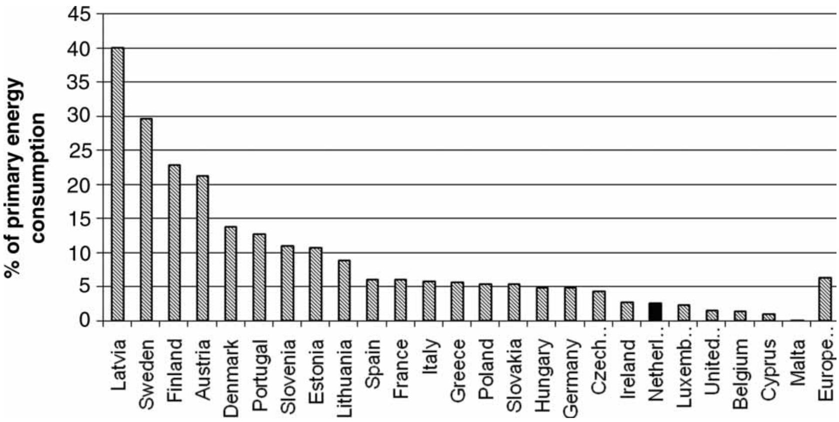

Figure 1. Share of renewable energies in primary energy consumption in European Union countries 2005 (EuroObserv'ER).

not necessarily remarkable, because innovation journeys with new technologies are always non-linear and unpredictable (Van de Ven et al. 1999; Geels and Raven 2006). Innovation journeys without some failures and setbacks do not exist. Renewable energy innovation in the Netherlands, however, seems to suffer from *recurring* failures and problems. Hence, the article aims: (1) to provide an empirical analysis of renewable energy innovation journeys, with particular attention for recurring patterns and mechanisms, (2) derive policy lessons from the analysis.

The analysis uses strategic niche management (SNM) as conceptual framework. SNM is based on a combination of two theories of technological change: social constructivism and evolutionary economics (see also Schot and Geels in this special issue). The social construction of technology (SCOT) approach analyses technological change as the outcome of interactions between various social groups (e.g. researchers, firms, policy makers, users, special-interest groups) (Bijker, Hughes, and Pinch 1987). SCOT particularly highlights socio-cognitive dimensions such as interpretations and beliefs. Because new technologies are characterised by 'interpretative flexibility', social groups often have different ideas and views. These ideas and interpretations influence the actions of actors and social groups with regard to investments, subsidies, pilot projects, contestations, and struggles. Social coalitions and cognitive interpretations may eventually stabilise as a result of learning processes and network building. SNM builds on SCOT, seeing technological change as socially enacted process, in which learning (changing interpretations) and network building are two crucial processes. Building on the sociology of expectations (Van Lente 1993; Brown and Michael 2003), SNM adds a third process: the articulation of expectations. These future-oriented visions not only guide actor's activities, but can also be used to interest and enrol other actors, thus broadening the social networks.

From evolutionary economics, SNM borrows the idea that new technologies require protection from mainstream market selection. This idea comes from biological evolution theory, which argues that new species emerge in geographical niches that are separated from a parent population (Mayr 1963). For technological change, such niches are socially constructed, consisting of social networks and actors that are willing to invest time and resources in a fledgling technology, because they believe in its potential (Schot and Geels 2007). In the case of renewable energy innovations, for instance, policy makers have provided such protection through subsidies and regulatory adaptations. SNM has further evolutionary connotations because of its attention for the alignment of variations (new technologies that often arise from R&D) and selection environment. SNM particularly focuses on bridging the 'valley of death' between R&D and market introduction. SNM-scholars have shown that concrete and real-life experimental projects (R&D, pilot, and demonstration projects) play an important role in that respect (Kemp, Schot, and Hoogma 1998; Hoogma et al. 2002; Raven 2005; Geels and Raven 2006). These projects bring together actors from the variation environment (researchers, firms, technology developers) and selection environment (users, policy makers, special interest groups), facilitate network building, stimulate learning processes and produce outcomes that may lead to adjustments in expectations.

The combination of SCOT and evolutionary economics allows SNM to open up the black box of technology. While evolutionary economics tends to operationalise 'learning' as R&D investments, patents and information accumulation, SNM additionally looks at the *content* of learning and the changes over time in perceptions, ideas and cognitive frames. With regard to networks, SNM not only looks at knowledge flows and exchange (of products, money and information), but also at *social* dimensions such as coalitions, trust, conflicts, and tensions.

Using SNM as conceptual framework, Section 2 provides 30-year descriptions of four niche-innovation trajectories: wind turbines, biomass, fuel cells and hydrogen, and photovoltaic (PV). These descriptions focus on the three main SNM-concepts: (1) social networks dynamics related to innovations; (2) expectation dynamics (visions, claims and counterclaims), and (3) learning processes. Section 3 provides a more systematic analysis of recurring patterns and mechanisms across the four cases. Section 3 also formulates policy conclusions.

Given the social enactment characteristics of the theoretical framework, the analysis belongs to the 'process theory' tradition in social science. Recent articles and special issues distinguish process theory from variance theory (Petttigrew 1997; Van de Ven and Poole 2005).[1] *Variance theory* explains (change in) outcomes as the product of independent variables (causal factors) acting on dependent variables. *Process theory* focuses on *events* rather than causal factors (Abbott 1992). Events are enacted by actors who make decisions, undertake actions and react to each other. Taking the notion of path dependence seriously, process theories explain outcomes as the result of temporal *sequences of events* and the *timing* and *conjunctures* of event-chains.

Process theory assumes that the world is made up of entities (people, organisations, technologies) that participate in events ('enactment') and may change their interpretations, preferences and networks. Because of this ontology, process theories use particular methodologies. *Variance theories*, which aim to estimate the relative importance of causal factors, usually collect quantitative data (facts, figures) that can be processed with statistical methods. *Process theories*, on the other hand, tend to adopt qualitative, interpretive methods (e.g. case studies), because they are rich in context and allow 'process tracing' of event chains and social interactions. Process theorists often use narrative methods, because they can capture fuzzy and unfolding processes (Abbott 1992; Griffin 1993). Some narratives, however, only describe 'one damn thing after another'. To turn case *histories* into case *studies*, narrative plots should be used to provide more analytical focus (Pentland 1999).

Pettigrew (1990) suggests further analytical steps. Instead of case histories, he advises scholars to write *analytic chronologies*. While an analytical chronology lays out the narrative, 'there is an explicit attempt to interpret and explain' the process (p. 280). The aim is not to tell the story 'as it really was' (an unrealistic ambition, partly, but not only, because of space constraints), but to use narrative plots to provide more selective analytical focus. Section 2 uses the three main SNM processes in that respect. Pettigrew (1990, 280) also suggests a further step towards *interpretative theoretical cases* that make 'both a more explicit attempt to interpret the narrative but also to link emerging conceptual and theoretical ideas inductively derived from the case to stronger analytical themes'. In that respect, Section 3 identifies more general analytical patterns and mechanism.

With regard to data, we use secondary sources, refer to academic publications in the literature, and draw from our own work, which is based on archival research (institutional and private archives), interviews, journals, reports, books, newspapers and internet sites. Elaborate descriptions of this research can be found elsewhere, e.g. studies of the electricity system (Verbong and Geels 2007), renewable energy (Verbong et al. 2001), co-firing of biomass and coal (Raven 2006), and biomass digestion (Geels and Raven 2006).

2. Description of niche-innovation trajectories

2.1. *Wind energy*

Wind energy was regarded as a promising renewable energy option for the Netherlands. Despite continuous efforts from the 1970s onwards, wind energy still is a minor niche, although Dutch offshore potential is considerable. Moreover, it faces several serious problems. The difficult development trajectory can be explained by a combination of a technology push approach, tensions in the social network and limited learning, resulting in a tarnished symbolic image.

Expectations dynamics

Following the first energy crisis in 1973, policy interest in wind energy rapidly increased. The first national energy research program on wind energy started in 1976. The official goal was to investigate the potential of wind energy, but the general vision was that the Netherlands (and Dutch industry) should become a global leader in this field. References to the glorious past of Dutch windmills served to legitimate a national research program. The outcome of this first program was confirmation of the view that wind energy was a promising option and recommendations for more research. In the early 1980s, a national goal for wind energy was agreed upon: 1000 MW in 2000. Although it became obvious during the 1990s that this target would not be met, it remained the official target (Verbong et al. 2001).

Because actors from the existing electricity regime dominated the social networks (see below), certain ideas guided the visions on wind energy. There was consensus that large-scale turbines, preferably clustered in wind parks, were the best way forward. However, the grass roots movement contested this large-scale vision. It succeeded in creating a decentralised line within the research program, focusing on small autonomous turbines. Learning processes in the late 1980s and early 1990s ran into problems for both designs (see below). Experiences in Denmark showed that gradual upscaling of small turbines was a better innovation journey (Kamp, Smits, and Andriesse 2004). Although Dutch actors also embraced this idea in the mid 1990s, it was too late to save the Dutch wind turbine industry.

In the late 1990s, concerns about climate change stimulated wind energy, which was (still) regarded as one of most important Dutch renewable energy options, but the implementation of wind energy encountered many problems such as local opposition and a weakening of its symbolic image. Public opinion expressed more concerns about landscape disturbance (wind turbines obstructing wide 'open sky' views) and 'bird shredding'. Grid operators increasingly saw wind turbines as unreliable and a danger to the stability of the electricity system (because they provide electricity on an intermittent basis) and politicians came to perceive wind turbines as a waste of tax money and a not very cost-effective way of reducing greenhouse gases.

Social network

The social network in the 1970s consisted mainly of representatives of the incumbent electricity regime: research institutes, large companies and electric utilities. These actors thought that only large turbines were a feasible option. Hence, R&D focused on large MW-size turbines, based on design knowledge from aeronautics. From the start the utilities played an ambiguous role (Verbong 1999). They were initially sceptical about wind energy's potential but sympathetic to (subsidised) initiatives.

The first tensions in the network were played out in the early 1980s. The utilities argued that they should have control over the first wind park, because its functional characteristics were similar to power plants. They succeeded in wrestling the park out of the national program framework, creating frustrations amongst other actors. Relationships between the utilities and technology suppliers further deteriorated, when the park failed because of unreliable wind turbines. The company that supplied the turbines almost went bankrupt. Another industrial company quit participation, complaining about the turbine selection procedure and arrogant behaviour of the electricity sector. The result of these negative experiences was that the attitude of the electricity sector and large industrial companies towards wind energy became more hostile (Verbong 1999).

Despite the disappointments and tensions in the 1980s, the Dutch position around 1990 was still good in an international perspective (Bergek and Jacobsson 2003): (1) there were three middle-sized turbine producing companies, supported by a few producers of rotor blades and other components; (2) the knowledge infrastructure was well developed, especially at Delft university and ECN (the Energy Research Centre of the Netherlands); (3) the utilities formed a foundation for the large-scale implementation of wind turbines, with financial support from the government, and (4) the government reached an agreement on wind turbine sites with seven Provinces. Ten years later, however, ambitions were shattered and the Dutch wind industry was overrun by Danish turbine producers. Although the Dutch companies switched to the Danish design, they could not keep up with the international companies who benefitted from first mover advantages and scale economies (Kamp, Smits, and Andriesse 2004).

The 1989 Electricity Law enforced a separation of production of electricity. While utilities remained responsible for production, the law introduced Energy Distribution Companies (EDCs) as a new actor, who were responsible for electricity distribution and consumer markets. This new actor provided new dynamics because EDCs stimulated wind energy (and other renewable sources) (Verbong and Geels 2007). Although EDCs put most of their efforts and resources in cogeneration of heat and power (CHP), they also stimulated the 'green electricity' market through advertising and image-building campaigns and constructed several wind energy parks (Hofman 2005). Nevertheless, the government did not achieve its official target. Only 450 MW of wind turbines were installed in 2000 (instead of 1000 MW).

The implementation problems were related to increasing tensions between the national policy level, where ambitious targets were set, and the local policy level, which was responsible for implementation, siting and permit procedures. The national level, which focused exclusively on the contributions of wind energy to climate change policies, often neglected possible benefits, sensitivities and opportunities on the local level. Because policy makers focused primarily on large scale applications and regime actors, they neglected broad-based institutional capability building (Breukers 2007).

Learning processes

In the 1970s and 1980s, learning focused mainly on technological aspects. The development of large breakthrough designs proved to be difficult (Kamp, Smits, and Andriesse 2004). Outcomes of learning processes were disappointing, because most large turbines broke down or did not function. Danish firms, in contrast, conquered the market with a bottom–up approach: they started with small-size turbines, and subsequently upscaled them (Van Est 1999). The innovative two-bladed design, favoured by the Dutch (and also Americans and Germans) lost out to the more conservative three-bladed Danish design (Kamp et al. 2004).

Failures also occurred in decentral designs, because the assumption that wind energy systems could function reliably without grid back-up, proved to be erroneous. These learning processes hardened the vision that only grid-connected wind parks had a future. Hence, the relationship with the existing electricity regime was seen as crucial for further development of wind energy (Verbong 2001).

Another issue was wind energy's impact on the electricity system. Because of wind fluctuations and unpredictability, the electricity sector estimated that only 650 MW of wind turbine capacity could be connected without endangering the system. This claim was contested by ECN, which made higher estimates (2500 MW) (Verbong 2001). The underlying issue was (and is) that wind turbines require the presence of spare capacity which can provide backup during windless periods. Normally, utilities paid electricity suppliers for the amount of electricity delivered to the grid, topped up with a 'capacity fee' based on savings in installed capacity. But for wind turbines, the electricity sector did not want to pay such a fee, arguing that they did not really replace existing production units. Wind energy promoters fiercely contested this principle, because low feedback tariffs increased the price gap between wind energy and regular electricity. The principle thus formed an important barrier for local initiatives by co-operatives and private wind associations. Despite these protests, utilities refused to pay 'capacity fees'. Another financial barrier for wind energy suppliers came from additional costs that utilities charged for connecting wind turbines to the grid. Both problems soured relationships in the social network behind wind energy.

In 1996, some conditions improved because of the introduction of an energy tax (REB). Because renewable energy was exempted from this tax, the price gap between 'green' electricity and normal 'grey' electricity was reduced. The tax exemption was supplemented by 2 cents/kWh for production support (Van Rooijen and Van Wees 2006). These support measures enabled wind energy to overcome the two previously mentioned economic barriers (the unpaid capacity fee and grid connection costs). Now 'green' electricity was about the same price as 'grey' electricity, which stimulated households' demand: the number of green electricity consumers rapidly increased from 16,000 in 1996 to 1.4 million in 2002 (Van Rooijen and Van Wees 2006).

From 1996 onwards, contributions from wind energy grew steadily, but the expansion also led to new problems, especially in the process of societal embedding. Local environmental and local interest groups increasingly opposed new wind energy projects, complaining that wind turbines disturbed the natural landscape, acted as 'bird shredders', and were noisy, ugly objects. These protests were the main reasons that wind energy targets for 2000 were not met. After 2000, offshore wind parks were seen as a promising solution, because they avoided on-land problems, but permit-procedures, negotiations with nature conservationists and uncertainty over financial support schemes delayed these projects.

This uncertainty was due to new policy changes in 2003. The underlying problem was that the rapid increase in consumer demand for 'green electricity' could not be met with national production alone. Hence, imports of renewable electricity increased rapidly from 1.5 GWh in

2000 to 10.5 GWh in 2002 (www.cbs.nl). In 2002, only 26% of 'green electricity' was produced domestically (Van Rooijen and Van Wees 2006). The unintended effect of renewable energy subsidies was that Dutch tax money flowed to international suppliers. Hence, a new government stopped the demand-oriented REB exemptions in 2003, replacing it with the supply-oriented and technology specific MEP-regulation (Environmental Quality Electricity generation). The MEP provided a fixed feed-in tariff to renewable electricity producers plus an additional ecotax exemption. The new MEP-scheme was initially set for 10 years, but within 2 years the minister of Economic Affairs announced a major downscaling, because the number of proposals for wind parks was much larger than expected, something that would imply major increases of the MEP budget. The minister thus excluded new offshore wind and large-scale biomass projects from MEP scheme. Only two offshore wind parks acquired financial support. In another twist to this story, the government abruptly announced the end of the MEP-scheme for all new projects, including small-scale projects, in August 2006. The government argued that the Netherlands would reach the EU goal (9% renewable electricity in 2010) with existing projects. Continuation of the MEP-regulation was thus seen as too costly and not really necessary.

These frequent changes in regulations and subsidy schemes and the refusal to support the industry over an extended period of time (as the Germans did) have given the national government an image of unreliability. Moreover, a persistent problem is the neglect of societal embedding of wind energy, with policy focusing primarily on the technical side of innovation (Breukers 2007).

2.2. *Biomass*

Biomass exists in several forms (e.g. waste, sludge, manure, straw, wood) and can be used for electricity generation through several processes (e.g. digestion, gasification, burning). The description starts with anaerobic biomass digestion, which was one of the first Dutch bioenergy technologies in the late 1970s; it subsequently experiences ups and downs. Next, we turn to waste incineration and co-firing of biomass and fossil fuels (coal and later also natural gas), which now provide the largest biomass contribution to renewable energy, but also face opposition from environmental and local interest groups.

Expectation dynamics of biomass digestion

Biomass digestion in an oxygen free environment produces biogas, which contains methane that can be used to generate electricity or heat. Visions on manure digestion were highly influenced by external factors and emerging problems within the agricultural and waste regime. In response to high oil prices in the late 1970s, a small network of farmers and agricultural researchers began to investigate small *farm-scale* manure digestion as a source of energy. Technical problems and (after 1986) decreasing oil prices lowered the expectations of this option.

By the mid 1980s, visions shifted towards large centralised plants. The functional focus was less on the production of biogas and more on manure processing (transforming it into less environmentally damaging substances). Expectations were very high, because centralised plants seemed a solution to the major manure surplus problems in the agricultural regime, but negative outcomes of learning processes created major disappointments a few years later, marking the end of the biogas hype. The backlash was that manure digestion was perceived as not feasible and manure digestion disappeared from the policy agenda.

In the late 1990s, interest in manure digestion was revitalised because of climate change and energy security concerns. Product champions pointed to the successful application of biomass digestion in Denmark and Germany, where manure digestion was developed as a multi-functional technology targeting problems in agriculture, energy and waste regimes (Geels and Raven 2006). Despite the new enthusiasm, total contributions to renewable energy are still small.

Social network

Farm-scale manure digestion in the late 1970s was pioneered by actors outside the energy regime. Projects were set up by agricultural researchers and individual farmers. Research was supported in the framework of a national research program, funded by the government.

In the mid 1980s, when centralised plants were seen as solution to manure surplus problems, more powerful agricultural regime actors took over (e.g. national farmers' organisations, the Ministry of Agriculture, national banks). These regime actors were under much societal and political pressure because of manure problems. The manure digestion network crumbled in the mid 1990s, because of negative experiences and costly failures.

For some years, no activities took place. In the late 1990s, however, manure digestion re-emerged with research institutes, consultants, energy distribution companies and several technology suppliers forming a new advocacy coalition (Raven 2005).

Learning processes

Experimental projects in the late 1970s and early 1980s encountered many technical and economic problems (e.g. sulphur contaminations that damaged gas turbines, lower biogas yields than expected). Decreasing oil prices after 1986 further damaged the economic viability of farmscale manure digestion, leading to a decline in projects (Geels and Raven 2006).

In the mid 1980s, the focus shifted to centralised biogas plants and manure processing. A large plant was constructed in 1988 (Promest), which was about 15 times larger than previous farmscale plants. This rapid upscaling created a range of technical and operational problems. Nevertheless, and despite warnings from consultants, the plant was enlarged with a factor 6 in 1990. Investment costs were €100 million, 40% of which came from investment grants from the Ministry of Agriculture. The enlarged plant opened in 1993. But technical and commercial problems rapidly became so large that the plant was closed in late 1994 (Geels and Raven 2006).

Meanwhile, German and Danish actors experimented with co-digestion, i.e. the addition of biomass sources (e.g. fatty wastes) to manure. This resulted in higher biogas yields and in technically stable and economically feasible biogas plants (Geels and Raven 2006). In the late 1990s, Dutch product champions pointed to these positive learning processes, arguing that biogas plant were multi-functional with environmental benefits for the energy, agriculture and waste domains. Policy makers also developed new interests in manure digestion, but the addition of waste products created legislative and permit problems (due to conflicting regulations for waste and agriculture). Legislative changes in the early 2000s led to new manure digestion projects.

Expectation dynamics and social network of waste and co-firing

Energy from waste has long been an important alternative energy source, although the government only recognised it officially as a sustainable source in the 1990s. In the early 1980s the government made a distinction between waste (like sludge and demolition wood) and biomass (cultivated energy crops). As energy from waste grew rapidly during the 1980s this distinction became blurred in official reports. Biomass was increasingly considered to include almost any organic fuel resource.

Waste was attractive to energy regime actors, because it offered them a relatively inexpensive fuel; utilities could earn 'gate fees' that would otherwise be paid for the dumping of waste streams.

In the early 1990s, utilities introduced co-firing of biomass and fossil fuels on a small-scale (Raven 2006). An exemption from the energy tax, introduced in 1996, made biomass co-firing financially even more attractive for the energy companies (Hofman 2005). Another driver for co-firing was pressure from the government. Increasing concern over climate change translated into stricter policies from the minister of Environmental Affairs. He threatened to close down coal-fired plants or to force a switch to natural gas. To avert this threat and reduce CO_2 emissions, utilities increased the level of biomass in coal-fired plants. Because of these activities, co-firing rapidly increased after 2000, becoming the largest renewable energy option (Figure 3).

Protests against these developments came from environmental groups who contested the official vision on biomass in the 1990s. They argued that waste was not sustainable and should be distinguished from biomass, which could be a sustainable form of energy. Environmentalists argued that plants that co-fired waste should fall under the stricter regulations from the waste regime. The utilities argued that waste in co-firing plants should be considered as biomass, which implied that certain emissions were allowed to be higher than for pure waste incinerators. These conflicting views led to legal struggles around permit procedures for new co-firing plants (Raven 2005). These legal procedures caused delay, and courts often ruled in favour of the plaintiffs. Nevertheless, the government broadened the definition of biomass to include all organic streams that can be used for energy production, including manure, sludge and demolition wood. Even the organic part of waste combusted in incinerators was (financially and statistically) recognised as a renewable energy source (Raven 2007). In the Third Energy White Paper (1995), the government expressed the vision of biomass as the main renewable option for the short- and mid-term.

Learning experiences

The expansion of co-firing was possible as a result of technical learning, which was relatively easy because regime actors could build upon existing competencies with coal combustion. Positive experiences showed that more biomass could be added than was initially expected, in particular when making use of more advanced technologies such as gasification. Although expectations about this more advanced technology were high, learning processes in the mid 1990s at a concrete biomass gasification plant (Amer plant), were negative. Despite a major re-design, the technical problems were not solved sufficiently (Raven 2006). Hence, regime actors turned back to more incremental ways of co-firing. Still, problems and uncertainties remained, for instance about the availability of biomass, about the development of a biomass market, about the impact of co-firing on the life span of power plants, and about the best technological route (Raven 2005). Recently, environmental organisations expressed concerns about two other issues: (1) competition between use of biomass for food production and for energy production and, (2) negative environmental impacts of large scale cultivation of energy crops, particularly in developing countries. Policy changes in subsidy schemes also contributed to uncertainty and, as a result, a sharp decline of co-firing in 2006 (Figure 2). This decline indicates that the commitment (and lock-in) from utilities to co-firing is not complete. Because co-firing is a dual-use technology, utilities can easily abandon biomass and switch back to normal practice if conditions become unfavourable.

2.3. *Fuel cells and hydrogen*

Fuel cells and hydrogen have been promising options for quite some time, with expectations displaying a hype cycle pattern. Fuel cells received much attention after successful application in the international space programs (1960s). In the 1970s and early 1980s, hydrogen came to be seen as an alternative energy carrier, but not as sustainable energy. More recently, the concept of

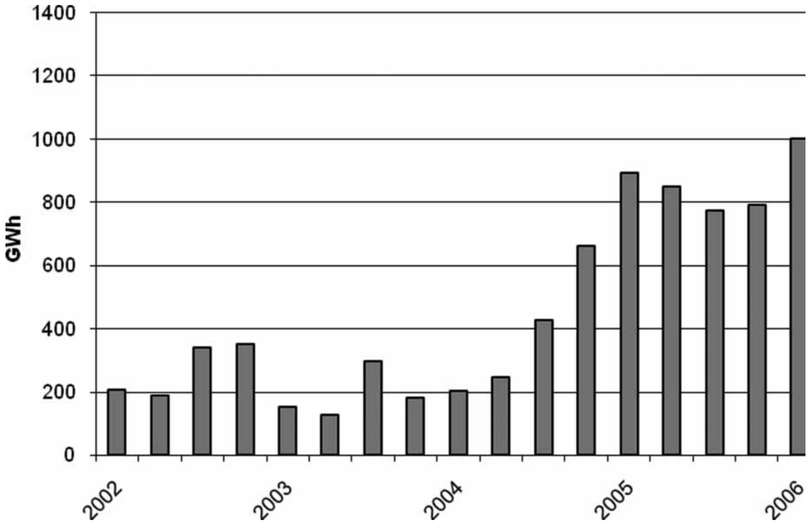

Figure 2. Development of co-firing of biomass 2002–2006 (http://statline.cbs.nl).

a hydrogen economy has become popular, because of its promise to solve many energy problems, in particular when the hydrogen is produced with renewable energy sources (Romm 2005).

Expectation dynamics

Interest for fuel cells emerged in the Netherlands in the early 1980s, when energy prices were high. International development efforts increased substantially in the USA and Japan. Pointing to a large US fuel cell demonstration project, industrial actors and researchers convinced the Ministry of Economic Affairs to start a dedicated R&D program to build up a new industry around fuel cells, which potentially had high conversion efficiencies and a lack of polluting waste products. In 1984, the Molten Carbonate Fuel Cell (MCFC) was selected as the most promising option. High expectations about this technology and the promise that a research program might help create a new Dutch industry were crucial elements in legitimating the funding for the second-largest energy R&D programme in the 1980s and 1990s (besides coal gasification). With regard to commercial prospects, the proponents and product champions promised that the MCFC project would deliver a competitive technology within 15 years. These promises were repeated regularly during the project, although outside consultants warned repeatedly about the lack of market demand, but the product champions went ahead anyway, pointing to international developments and the need to keep up. The Dutch government spent about €100 million, providing about 80% of total fuel cell funding. Despite these investments, the fuel cell innovation trajectory failed in the mid 1990s (Van der Hoeven 2001).

An important reason for this failure was that the vision about the main application domain changed from power generation to transport applications (fuel cell vehicles). In response to climate change pressures, car manufacturers became more interested in hydrogen powered cars, boosting new expectations. This change in vision halted MCFC development, because its technical characteristics (high operating temperatures) did not fit well with this new envisaged application domain. However, this new vision also created new opportunities for other fuel cell designs (e.g. the Proton Exchange Membrane FC (PEMFC), the Solid Oxide FC (SOFC)), which also benefited from broader enthusiasm about the hydrogen society.

Social network

Although there had been some previous R&D on fuel cells at universities and companies, a new network was build up in the 1980s. Although R&D activities were concentrated at ECN, the Ministry insisted on the participation of industrial partners. The Dutch steel company Hoogovens was enrolled in the network, but quit in 1988. Subsequently, two medium-sized companies were enlisted, because of their expertise in engineering and machine building (Schaeffer 1998). Also potential users were included in the network: the joint organisation of Dutch electricity producers (SEP) as 'launching customer' and EDCs as partners, because they saw fuel cell powered plants as an attractive option for small-scale decentralised generation (up to a few MW).

With regard to funding it seems that the Ministry of Economic Affairs was somewhat naive about the commitment and participation from industry. As soon as industry showed some interest, the Ministry provided subsidies (about 80% of total costs in this case), but real commitment was not very high, because of problems in the social network. The Ministry basically forced the two medium-sized companies to join after Hoogovens left. Under pressure, these companies participated half-heartedly. Furthermore, relations with potential users (especially energy distribution companies) also soured during the project. They were disappointed that the project did not deliver a product they could implement (Van der Hoeven 2001).

Learning processes

Despite some initial successes, learning processes advanced slower than expected. There were persistent technical problems: because of high operational temperatures of the MCFC (800–1000 °C) and the chemical substances used, cell components suffered corrosion. Because of these challenges, the program focused on technological learning, paying limited attention to market prospects. Technical learning and R&D activities (at ECN) focused primarily on the fuel cell itself, and neglected other components of a fuel cell system. This led to problems when researchers eventually assembled a system and learned that several design specifications of the fuel cell negatively impacted the whole system, making it very large and expensive. The project partners concluded that this concept would not produce a commercially viable product. In 1993 the project was cancelled, because there was no money or time to select another design (Van der Hoeven 2001). The EDCs were disappointed and tried to settle financial arrangements legally, but the SEP was satisfied, because they wanted to know if the MCFC was an option for large scale generation. The project showed that fuel cell power stations were technologically feasible, but economically not.

The project was restarted within 2 years, because ECN (and the Ministry) still believed in a future for the MCFC technology. The focus shifted to smaller systems for niche applications and, based on previous lessons, more attention was paid to commercial requirements (Van der Hoeven 2001), but in 1998, the project was again cancelled, signalling the end of MCFC research. Although the MCFC made good technical progress, it was increasingly seen as obsolete as expectations shifted to other fuel cell types, in particular the PEMFC and the SOFC. The main reason was a change in vision and economic opportunities (shift from power generation to transport applications) (Van der Hoeven 2001; Van den Hoed 2004).

2.4. *Photovoltaic (solar PV)*

Because of the small scale character of photovoltaic applications and because of the Dutch geographical position and climate, PV initially only received interest from researchers at universities.

In the early 1990s, perceptions of PV's potential improved substantially, but shifting policy priorities in the late 1990s caused stagnation in PV implementation, although societal support for PV is still high.

Expectation dynamics

In the 1970s, PV was not part of sustainable energy visions, because of the small scale of applications. Dutch policy makers and experts thought that PV was unfeasible in the Netherlands (Verbong 2001). In the early 1990s, however, official white papers on energy policy considered PV the most important renewable option for the long-term future. In the Third Energy White Paper (1995), for instance, the government denoted PV as the main long-term option, next to biomass. This remarkable shift was caused by active lobbying by researchers and positive learning processes (see below). Also, Shell, a powerful actor in the energy domain, embraced PV in its long-term scenarios (e.g. 'The Evolution of the World's Energy Systems', 1996), expecting it to be a major energy source by 2050. The Shell vision influenced policy makers and NGO (Verbong 2001).

Although visions and promises were high, electricity from PV remained more expensive than electricity generated by coal or gas fired plants and other renewable options. Technical development therefore focused on higher conversion efficiency of solar cells and lower production costs (Perlin 2002). Researchers promised that learning effects and economies of scale would eventually make this technology competitive with electricity from fossil fuel power plants. However, despite technological progress, the kWh price remained high. In the late 1990s, policy analysis re-evaluated available options for greenhouse gas reduction, using two criteria: (a) the contribution to greenhouse gas reduction, (b) cost-efficiency. PV scored poorly on both criteria: total contribution to renewable energy was small and it was very expensive. High PV expectations in the policy domain subsequently collapsed and the policy focus shifted back to wind and biomass.

Social networks and learning processes

Research on PV started at universities and research institutes. The high-tech character of the technology, closely related to the semiconductor technology, offered excellent opportunities for research (and funding). For a decade, the network remained relatively small, but sustained lobbying succeeded in persuading policy makers, industrial companies, utilities and environmental organisations to support research and demonstration projects (Verbong 2001). This facilitated learning processes, which demonstrated that PV could be applied in the Dutch climate. Projects abroad also contributed to more positive perceptions of PV in the early 1980s. By the late 1980s, there were efforts to develop grid-connected systems, but high costs provided important stumbling blocks.

In the early 1990s, the environmental movement embraced PV, because it had grown increasingly sceptical about other renewable energy sources. Broad societal support led to vastly increased budgets for R&D and PV pilot projects. Greenpeace, but also EDCs such as Nuon, started ambitious projects to encourage the diffusion of PV panels among Dutch households (Verbong 2001).

Tensions between the government and Shell then soured the social network. Shell, which owned a small production facility (Shell Solar), wanted to expand its PV activities in the late 1990s. The government initially stimulated Shell with the transfer of knowledge and technology from Dutch universities and ECN. Nevertheless, Shell decided to build its new PV production plant in Germany, which offered better protective and stimulating policies. This was a major disappointment for the Ministry of Economic Affairs. This failure in industrial policy was widely criticised for low reliability, lack of long-term commitment to solar energy (as the Germans did), too rapid introduction of market pressures, and insufficient support and protection, which is required for radical innovations (Verbong 2001).

3. Analysis and conclusions

Niche-innovation trajectories have long histories (30–40 years) and are non-linear processes with many ups and downs. The previous descriptions showed a high degree of trial and error and 'muddling through'. 'Muddling through' does not mean that no progress can be made. In fact, the share of renewable electricity has risen substantially, from less than 1% of total electricity consumption in 1990 to 4.3% in 2004 and 6.6% in 2006 (see Figure 3 for data on total production). Initially, renewable electricity came primarily from burning waste. Gradually, wind has become more important, supplemented from 1998 onwards by the rapid expansion of co-firing of biomass and fossil fuels. The use of biomass accounted for 4.3% of the national electricity production in 2005, but there has been a sharp decline in production in the second half of 2006 (Figure 2).

Policy makers like to claim this growth as evidence of the success of their policies. The previous descriptions, however, demonstrated that such claims are too easy. Instead of effective policies, we found costly failures, hype cycles, changing visions and policy priorities, and limited learning capability. The following two sub-sections use the three niche-internal processes (expectation dynamics, learning processes, social network dynamics) to provide a more systematic analysis of recurring patterns and mechanisms in Dutch niche development trajectories and policy dynamics.

3.1. *Patterns in niche development trajectories*

A. *Expectations*

High expectations and backlash. All niche-innovation trajectories were characterised by high initial expectations, e.g. wind energy in the 1970s, fuel cells in the mid 1980s, and PV in the

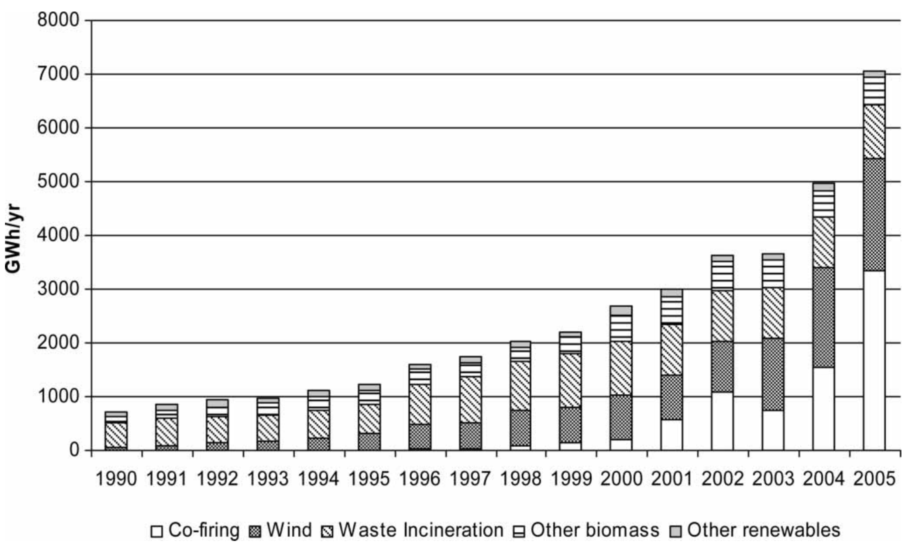

Figure 3. Dutch renewable electricity production (GWh per year) (data from Central Bureau of Statistics, www.cbs.nl).

early and mid 1990s. Product champions made high promises early in the trajectories to attract attention and funding. The technological visions triggered enthusiasm for some time, but were subsequently followed by disappointments. The general pattern is that expectations were too high, technical problems were bigger than expected, and implementation was slower than anticipated. So, most niche trajectories experienced a hype–disappointment cycle. This is not uncommon for innovation journeys, but our impression is that the peaks and valleys are more extreme than in other countries (see, for instance, the more gradual innovation journeys in Denmark (Garud and Karnoe 2003).

Expectation successions. Niche trajectories succeeded each other in the sense that disappointing outcomes and 'negative' learning processes in one trajectory often led to increased expectations in another trajectory. In the early 1990s, there was a shift from wind energy to biomass (for the short term) and PV (for the long term). In the early 2000s, there was a shift back from PV to wind energy.

This expectation dynamic also works in the other direction. Positive outcomes and learning processes in one trajectory may negatively influence the expectations of another trajectory. The present success of direct co-firing of biomass may become a barrier for the future development of more advanced technologies as gasification or pyrolysis. Figure 4 presents a schematic representation of expectation successions.

The mechanism behind this pattern is that policy actors face credibility pressures with regard to societal problems, such as sustainability. In societal debates they need to express faith in at least one promising solution. Policy makers are modernist actors who need to 'tell themselves forward'. They need to tell stories and make promises about how they will solve problems. This credibility pressure creates willingness to accept certain promises from product champions. It also explains why warnings about feasibility are often downplayed.

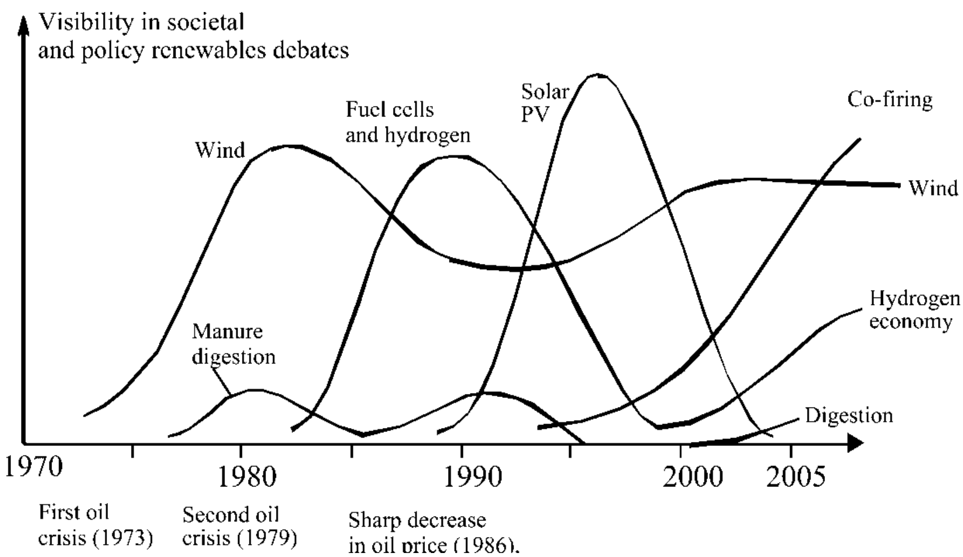

Figure 4. Shifts in visions in societal and policy debates.

B. *Learning processes*

Low quality learning processes. In most trajectories technological problems were underestimated. Regarding the molten carbonate fuel cell (MCFC), for instance, the problem of corrosion was much more persistent than the researchers wanted to believe, and regarding wind turbines, the transfer of knowledge from the aeronautic domain did not sufficiently take into account the much higher strain on rotor blades, leading to a string of broken blades. Although such problems are quite common with new technologies, they were insufficiently anticipated.

Technology push and focus on technological learning. All niche-innovation trajectories were characterised by a technology push approach, focusing primarily on R&D. Other dimensions of learning and articulation processes were relatively neglected (e.g. commercial prospects, societal embedding, legal procedures, societal stakeholders). This neglect negatively influenced subsequent implementation. Regarding MCFC, for instance, warnings about the lack of commercial feasibility were consistently ignored, contributing to the failure of the first phase. Lack of attention for the social acceptance of renewable energies led to major problems with wind turbines and biomass, which both experienced fierce opposition.

From 'stretch' to 'fit'. The growth in renewable electricity comes from options that are relatively close to the existing regime (have a 'fit' with existing rules, principles and practices). Innovation in the 1980s had more of a 'stretch' character, pioneering options that deviated substantially from the existing regime (and were more radical in that sense), but the late 1990s and early 2000s saw a move in the direction of 'fit' options that are closer to the existing regime. This applies not only to co-firing of biomass, but also to the CO_2 capture and sequestration that currently receives much attention. Regarding biomass, there were more radical technologies (like gasification), but these typically experienced more problems.

C. *Social networks*

Supply-side oriented innovation networks. Dutch energy innovation journeys have been dominated by a limited number of knowledge institutes (ECN, universities), large companies (Shell, utilities) and intermediaries (Senter-Novem). This composition of social networks, and the focus on R&D, led to the technology push approach, discussed above. This social structure seems to be a persistent feature of Dutch energy innovation. Although policy makers have adopted a discourse on innovation systems (which includes phrases such as 'user–producer interactions' and 'multi-directional knowledge flows'), real innovation practices still seem to be mainly R&D oriented. The government–industry–university relations have characteristics of 'old boy networks', which divide subsidies among themselves. For small firms, who are not part of the relevant networks, it is usually more difficult to get funding.

Narrow, closed networks. For most of the period, the social networks behind niche-innovations were narrow and closed. Outsiders were hardly involved. This was partly related to characteristics of Dutch innovation journeys discussed above, but technical characteristics also played a role. Photovoltaics, for instance, had a 'high tech' character, giving researchers a strong position in the PV network. Also modern wind turbines are 'high tech', building on knowledge from the aeronautical domain.

The main exception to this pattern was wind energy in the early 1980s, where a grass roots movement succeeded in setting up a decentralised research line in the national research programme. Local groups of enthusiasts also founded wind energy co-operations. Another exception is manure digestion, which was pioneered by farmers, researchers and technology suppliers in the agricultural domain, but renewable energy contributions from digestion have remained very small.

Network tensions. Although the social networks were narrow and closed, they were not harmonious, but strained. Technology developers and utilities clashed repeatedly. Government actions, which sometimes forced companies to participate in networks, also created tensions and damaged the willingness to cooperate (see also below).

Societal protest and contestation. Although 'renewable energy' as an abstract term is widely supported, concrete options are usually contested. Each renewable option has some disadvantages ('horizon pollution', 'bird shredding', emissions of heavy metals, stench, costs). Because Dutch institutional arrangements give stakeholders many options to protest, environmentalists and local inhabitants can easily frustrate or delay options they dislike. Wind energy and biomass projects experienced severe delays because of protests and legal procedures. Contestation was exacerbated by the technology push approach, which gave little attention to the societal embedding of new technologies. Because of the disappointing results during the 1990's, there appears to be more attention for stakeholder participation, which involves opposing groups earlier in the innovation process.

3.2. *Conclusions about policy*

With regard to Dutch energy policy, several patterns can be observed.

Link with industrial and innovation policy. Energy policy has been strongly linked to industrial and innovation policy. In all niche development trajectories industrial arguments were prominent. Wind energy, PV, and fuel cells were (at least partly) stimulated to support existing industry (Shell) or build new industries. These industrial interests have been important arguments for high levels of public funding of energy research. The exceptions were some biomass applications, which were either taken up by utilities themselves (and supported with other policy measures) or not perceived as part of the energy domain (biogas, which was sponsored by agricultural actors). The link between energy policy and industrial policy also occurred in other countries, where it had more success because of different innovation styles, e.g. more gradual upscaling in Denmark (Garud and Karnoe 2003; Kamp, Smits, and Andriesse 2004) and more stable protection and market creation in Germany (Jacobsson and Lauber 2006).

Instability and unreliability of policy. An important factor in Dutch industrial failures was policy instability. With regard to renewable energy, frequent changes occurred in regulations and subsidies, exemplified by the REB and MEP-regulations from 1995 onwards. Shifts in policy, almost every few years, created uncertainties and hampered private investments.

Low quality of network management. One problem was that firms were sometimes 'forced' to cooperate in projects, e.g. in the fuel cell project, leading to low commitments. Another problem is that policy makers were eager to accept promises from industry about commitment, technical feasibility, risks and future price/performance (in the case of fuel cells and PV), but policy makers appeared to have little competence to assess the robustness and quality of visions and promises. Money was made available, as soon as industry showed some interest. This seems to be a common characteristic of all large energy technology projects in the Netherlands (Verbong 2001). Industry does not invest in high risk, long-term technological projects, unless the government carries the financial risks, but thorough quality checks on technological promises were often absent.

Limited learning. Experiences in the 1990s and in other countries (Denmark, Germany) showed that regulatory stability and long term support were crucial for successful development of renewable technologies (Jacobsson and Lauber 2006). Policy analysts and consultants recognised these characteristics as key components for renewable energy policy, but these lessons were not internalised, as policy actions in the early 2000s demonstrate (frequent policy changes that created instability and uncertainty). Policy makers did not provide long-term guarantees and too rapidly abandoned innovations when setbacks occurred. They cut off protection measures too soon, and introduced market pressures when innovations had not yet stabilised. So, the lessons from the 1990s were either forgotten or not implemented (for political or financial reasons).

Bandwagon and circus dynamics. Another reason for policy instability is that renewable energy is highly politicised. Policy makers in this domain are eager to show successes and are therefore looking for positive stories. This enhances the pattern of expectation successions, described above. Policy makers jump on the bandwagon and thus reinforce hype cycles, but when setbacks occur a few years later, they become disappointed and the circus moves on to a new promising option. This gives Dutch innovation a hype-driven character, and makes policy unreliable (a common complaint by innovators). Changes in subsidies or regulations directly affect the feasibility of experiments and implementation projects.

These recurring characteristics of innovation journeys and policy combine into a Dutch renewable energy 'innovation style'. Compared to other countries such as Denmark and Germany, this style has not been very successful in nurturing the development of radical options since the 1970's. The renewable electricity expansion in the first years of the 21st century was carried mainly by options that are closer to the existing regime (and hence more incremental). We conclude that the Dutch innovation style may be substantially improved with regard to learning processes (paying more attention to social aspects), the construction of broader networks (including users and outsiders like NGOs and SMEs) and expectations (more critically assessing the promises articulated by the representatives of the vested interest and technology promoters).

Note

1. See the special topic forum on 'Theory development: Evaluation, reflections, and new directions' in the *Academy of Management Review* 24, no. 4 (1999); special issue on 'Processual research on management and organizations' in the *Scandinavian Journal of* Management 13, no. 4 (1997); special issue on 'Longitudinal field research methods for studying processes of organizational change' in *Organization Science* 1, no. 3 (1990).

References

Abbott, A. 1992. From causes to events: notes on narrative positivism. *Sociological Methods and Research* 20, no. 4: 428–455.

Bergek, A., and S. Jacobsson. 2003. The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries. In *Change, transformation and development*, eds. S. Metcalfe and U. Cantner, 197–228. Heidelberg: Physica/Springer.

Bijker, W.E., T.P. Hughes, and T. Pinch, eds. 1987. *The social construction of technological systems: new directions in the sociology and history of technology*. Cambridge, MA: The MIT Press.

Breukers, S. 2007. Changing institutional landscapes for implementing wind power. PhD thesis, University of Amsterdam.

Brown, N., and M. Michael. 2003. The sociology of expectations: retrospecting prospects and prospecting retrospects. *Technology Analysis & Strategic Management* 15, no. 1: 3–18.

Garud, R., and P. Karnoe. 2003. Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship. *Research Policy* 32: 277–300.

Geels, F.W., and R.P.J.M. Raven. 2006. Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). *Technology Analysis & Strategic Management* 18: 375–92.

Griffin, L.J. 1993. Narrative, event-structure, and causal interpretation in historical sociology. *American Journal of Sociology* 98, no. 5: 1094–133.

Hofman, P.S. 2005. Innovation and insitutional change. The transition to a sustainable electricity system. PhD thesis, University of Twente, Enschede.

Hoogma, R., R. Kemp, J. Schot, and B. Truffer. 2002. *Experimenting for sustainable transport: the approach of strategic niche management*. London: Spon Press.

Jacobsson, S., and V. Lauber. 2006. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology. *Energy Policy* 34, no. 3: 256–76.

Kamp, L.M., R.E.H.M. Smits, and C.D. Andriesse. 2004. Notions on learning applied to wind turbine developments in the Netherlands and Denmark. *Energy Policy* 32: 1625–37.

Kemp, R., J. Schot, and R. Hoogma. 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management* 10: 175–96.

Mayr, E. 1963. *Animal species and evolution*. Cambridge MA: Harvard University Press.

Ministry of Economic Affairs. 1995. *Third energy white paper*. The Hague: SDU.

Ministry of Spatial Planning, Housing and the Environment. 1989. *The national environmental policy plan*. The Hague: SDU.

Pentland, B.T. 1999. Building process theory with narrative: from description to explanation. *Academy of Management Review* 24, no. 4: 711–24.

Perlin, J. 2002. *From space to earth. The story of solar electricity.* Cambridge, MA: Harvard University Press.

Pettigrew, A.M. 1990. Longitudinal field research on change: theory and practice. *Organization Science* 1, no. 3: 267–92.

———. 1997. What is a processual analysis. *Scandinavian Journal of Management* 13, no. 4: 337–48.

Raven, R.P.J.M. 2005. Strategic niche management for biomass. PhD thesis, TU Eindhoven.

———. 2006. Towards alternative trajectories. Reconfigurations in the Dutch electricity regime. *Research Policy* 35: 581–595.

———. 2007. Co-evolution of waste and electricity regimes. Multi-regime dynamics in the Netherlands (1969–2003). *Energy Policy* 35: 2197–208.

Romm, J.J. 2005. *The hype about hydrogen. Fact and fiction in the race to save the climate*. Washington, DC: Island Press.

Schaeffer, G.J. 1998. Fuel cells for the future: a contribution to technology forecasting from a technology dynamics perspective. PhD thesis, Twente University, Enschede.

Shell. 1995. *The evolution of the world's energy system 1860–2060*. London: Shell International.

Schot, J.W., and F.W. Geels. 2007. Niches in evolutionary theories of technical change: a critical survey of the literature. *Journal of Evolutionary Economics* 17, no. 5: 605–22.

Van den Hoed, R. 2004: Driving fuel cell vehicles. How established industries react to radical technologies. Thesis, Delft.

Van der Hoeven, D. 2001. *Een Gedurfd Bod: Nederland zet in op de Brandstofcel*. Bergen NH: BetaText.

Van de Ven, A.H., D.E. Polley, G. Garud, and S. Venkataraman. 1999. *The innovation journey*. Oxford: Oxford University Press.

Van de Ven, A.H., and M.S. Poole. 2005. Alternative approaches for studying organizational change. *Organization Studies* 26, no. 9: 1377–404.

Van Est, R. 1999. Winds of change. A comparative study of the politics of wind energy innovation in California and Denmark. PhD thesis, University of Amsterdam, Amsterdam.

Van Lente, H. 1993. Promising technology: the dynamics of expectations in technological development. PhD thesis, Twente University, Delft: Eburon.

Van Rooijen, S.N.M., and M.T. van Wees. 2006. Green electricity policies in the Netherlands: an analysis of policy decisions. *Energy Policy* 34: 60–71.

Verbong, G.P.J. 1999. Wind power in the Netherlands 1970–1995. *Centaurus* 41, no. 1/2: 137–60.
Verbong, G., A. van Selm, R. Knoppers, and R. Raven. 2001. Een kwestie van lange adem. De geschiedenis van duurzame energie in Nederland 1970–2000. Boxtel: Aeneas Technical Publishers.
Verbong, G., and F. Geels. 2007. The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy Policy* 35: 1025–037.