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Upscaling emerging niche technologies in sustainable energy: an international comparison of policy approaches

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ABSTRACT

To speed up the transformation to low-carbon energy systems, transition policy approaches highlight the importance of purposive experimentation with sustainable niche technologies. An important policy challenge that has followed from various 'real' transition experiments concerns the crucial issue of 'upscaling' or 'aggregating' the niche technologies towards broader and more widespread application in society. To address the question '*which policy mix supports the upscaling of emergent niche technologies in a transition to sustainable energy systems?*' the paper adopts a comparative approach. Two successful cases where upscaling of emergent technology niches has taken place are contrasted with an unsuccessful fail case. The success cases entail the emergence and diffusion of bioenergy and biofuels in Sweden as well as windpower in Denmark whereas the fail case consists of biofuels in the Netherlands.

Keywords: sustainability transitions, niche technologies, technological innovation systems

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1. Introduction

To curb a looming energy and climate crisis, a large-scale shift towards low carbon systems in energy supply, distribution and use is considered necessary (Stern, 2008). This calls for broad changes not only on the technological level but also in economic, socio-cultural and institutional terms. The notion of sustainability transitions is often used in the literature to analyze the broad, system-wide interaction and co-evolution of new technologies, changes in markets, user practices, policy and cultural discourses, and governing institutions (Elzen et al., 2004, Geels et al., 2008). Studies in sustainability transitions have not only made a considerable scientific impact in the field of sustainability research and green innovation (see e.g. recent special issues in *Research Policy and Technology Analysis and Strategic Management*), this community also explicitly seeks to engage actively with policy practice and discourse. Especially in the Netherlands, transition policy approaches such as ‘Transition Management’ and ‘Strategic Niche Management’ have been burgeoning through active interaction between scientists and policy makers (Loorbach and Kemp, 2008). Recently, these approaches have started to internationalize, engaging with scholars and policy-makers in various other countries. This has stirred a lively debate about its validity and practical transferability to different contexts (see e.g. Shove and Walker, 2007 & 2008; Rotmans and Kemp, 2008; Kern and Smith, 2008).

To speed up the transformation to low-carbon energy systems, transition policy approaches highlight the importance of purposive experimentation with sustainable niche technologies such as wind turbines, battery powered vehicles, fuel cell vehicles, photovoltaic cells, organic food, biogas plants and biomass co-firing (Kemp et al., 1998; Raven, 2005; Luiten and van Sandick, 2007). The rationale for these transition experiments is to provide a vehicle for the ‘translation’ of the long-term visions and socio-technical transition pathways to sustainability in more concrete terms. This is supposed to be done by concentrating on search and exploration processes in which

firms, research institutes, universities and governments are navigating and negotiating their way forward through societal experiments with new technologies, gaining knowledge and experience along the way. An important policy challenge that has followed from various 'real' transition experiments concerns the crucial issue of 'upscaling' or 'aggregating' the niche technologies towards broader and more widespread application in society or, phrased differently, to accelerate the process from the initial 'niche' to a large scale transformation that replaces dominant (unsustainable) practices (Geels et al., 2008; Raven et al., 2010).

The challenge to induce upscaling processes points to considerable difficulties for transition policy to steer sustainable niches into the mainstream. Moreover, recent contributions have started to question the dominance of experiments as an instrument to increase the diffusion of emerging niche technologies and to speed up sustainability transitions, arguing for a broader policy approach (Smith et al., 2005; Smith et al., 2010; Markard and Truffer, 2008; Kern and Smith, 2008). This paper contributes to this discussion as it aims *to investigate the impact of different policy instruments to scale up emergent niche technologies in sustainable energy*. To do so, the paper addresses the following research question: *Which policy mix supports the upscaling of emergent niche technologies in a transition to sustainable energy systems?*

To address the question the paper adopts a comparative approach. Two successful cases where upscaling of emergent technology niches has taken place are contrasted with an unsuccessful fail case. The success cases entail the emergence and diffusion of bioenergy and biofuels in Sweden as well as windpower in Denmark whereas the fail case consists of biofuels in the Netherlands. To cater for a policy-oriented and comparative analytical framework, the paper draws on the technological innovation system approach (Carlsson & Stankiewicz, 1991; Jacobsson & Berke 2004; Hekkert et al., 2007). This framework makes explicit the relationships between innovation dynamics and policy.

The remainder of the paper will first review the extant literature for policy insights on upscaling of emergent technological niches. Section three will then outline the analytical framework to analyze the case studies. In section four the cases are analyzed, followed by conclusions and recommendations for further research.

2 State-of-the art: policy insights on upscaling emergent technological niches

There are various related strands of literature, which have been developed in the last decade, that address the notion of (sustainability) transitions; each with a specific view on upscaling. Broadly speaking, this involves the literature on socio-technical systems, including the Multi Level Perspective and Strategic Niche Management (SNM) and Transition Management (TM), and the literature on Technological Innovation Systems (TIS) (Markard and Truffer, 2008, Weber et al., 2006). All these perspectives acknowledge that the radical innovations needed to transform current energy production and consumption systems cannot be left to market coordination but require active support or protection from public policy. Therefore it makes sense to provide a brief overview of viewpoints and perspectives that are brought to bear by various authors.

Multi-level perspective

The notion of transition experiments is heavily influenced by the multi-level perspective on socio-technical systems (Rip and Kemp, 1998; Geels, 2002). A central tenet in MLP is the stabilizing influence of a socio-technical regime on innovation dynamics. Here, a regime is defined as "the coherent complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures" (Rip and Kemp, 1998, p. 338). By its very nature a regime seeks to retain its configuration, allowing only for incremental, path-following innovation and resisting transition. In contrast, 'niches' act as 'incubation spaces' dominated by uncertainty and experimental disorder. These are "protected spaces in which actors learn about novel technologies and their uses" (Geels, 2002, p. 365) that nurture novelty and protect radical innovations against mainstream market selection. Due to its emphasis on 'extraordinary' innovations, the niche level is often seen as the level where transitions pathways are initiated.

Strategic Niche Management (SNM)

Strategic niche management can be seen as a steering tool that has translated a number of insights from the multi-level perspective on socio-technical change and studies on niche technologies into a more practice and action-oriented context (see also Luiten and van Sandick for a similar approach). Here upscaling refers to increasing the scale, scope and intensity of niches by building

a constituency behind a new sustainable technology, setting in motion interactive learning processes and institutional adaptation, which helps to create the necessary conditions for the successful diffusion and development of those technologies (Kemp, Schot et al. 1998). This resonates with findings by Raven (2005) concerning the main success factors for governance of niche experiments: (1) the development of a broad and aligned network of niche actors in the experiment (firms, users, policymakers, entrepreneurs, etc.) (2) the heterogeneous set of niche actors has developed similar, or at least converging expectations about the experiment, based on tangible results from the experiment. (3) Learning processes take place that align the technical features of the niche experiment with its social dimensions (e.g. regulation, user preferences) and that induce the actors to reflect about their underlying norms and values about the niche experiment.

Transition Management (TM)

The literature on Transition Management also addresses the issue of scaling-up experiments (van den Bosch, 2010). Here scaling-up refers to the process by which sustainable practices that are initially deviant or unusual, become the dominant or mainstream in terms of thinking (culture), doing (practices) and organizing (structure). In terms of policy lessons, it is argued that 'management activities' in transition experiments should broaden their perspective. Most transition management, it is argued, is mainly concerned with its own idiosyncratic project and lacks strategic activities for scaling-up. However, this literature remains rather mute in terms of policy insights how to actually support upscaling. In addition it should be mentioned that the notion of Transition Management has been criticized for smoothing over conflict and inequality between different stakeholders, 'expecting far more than participatory processes can ever hope to deliver' (Shove and Walker, 2007, p. 768).

Technological Innovation Systems (TIS)

The TIS approach derives from the idea that technological innovation lies at the core of a transition process. These technological innovations are supported by a TIS, which can be defined as:

'A dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology.' (Carlsson and Stankiewicz, 1991) (p. 93).

TIS studies analyse a technological field by referring to systemic features, including actors, institutions, (sometimes) technologies and most importantly, all the interrelations between them (Carlsson et al., 2002b). The TIS concept has been successfully applied to develop an understanding of innovation processes as related to societal structures such as governments, universities, NGOs, intermediary organisations and the like. A recent series of studies focuses especially on TISs around emerging sustainable innovations (Bergek, 2002; Hekkert et al., 2007; Jacobsson et al., 2004). More specifically, Negro et al. (2008) have used the TIS approach to arrive at policy insights how to stimulate renewable energy technology. This study focuses mainly on policy implications based on innovation system failures, i.e. lack of a shared, long-term vision/expectations about the direction of transition pathways in government policy, lack of platforms for stakeholders to learn and experiment with new technology, lack of long-term financial support for radical innovation and, finally, lack of capabilities and strategic intelligence among government about transition pathways. The emphasis on innovation system failures as a rationale for (improved) government policy can partly be explained by the empirical studies informing these insights. All cases, i.e. biomass combustion, gasification and co-firing in the Netherlands, can be considered as unsuccessful in terms of large-scale diffusion. The focus on failure is further corroborated in later studies on this topic (Negro and Hekkert, 2010) in which 7 typical failures in the innovation systems of renewable energy technologies are identified. In addition to the above, they mention a ‘valley of death’ between the R&D phase and market introduction, unstable and frequently changing policy instruments and unrealistic expectations and criteria for new, renewable energy technologies.

Summary

The review of existing policy insights in the literature on SNM, TM and TIS reveals that all frameworks emphasize the importance of learning by doing in networks of stakeholders, long-term and stable government support for renewable energy and shared expectations about the direction of transition trajectories. This policy orientation draws to a large extent on a so-called deliberative rationality for policy-making (Kronsell and Bäckstrand, 2010). It encompasses participation, deliberation, communication and multiple actors’ engagement in problem solving and decision-making. While the benefits of this perspective should certainly be acknowledged in terms of arriving at highly informed and legitimate decisions, much in line with the idea of green deliberative democracy, it may also create a liability vis-à-vis the (environmental) effectiveness of these decisions (Kronsell and Bäckstrand, 2010).

In terms of policy impacts, SNM and TM on the one hand and TIS on the other, differ on one particular dimension. While SNM and TM are mainly concerned with policy recommendations and insights on the micro-level of individual projects and experiments (see also Raven et al., 2010), TIS pays more attention to policy instruments on a meso level, taking more account of networks of actors and institutional frameworks. In our analysis we choose to proceed with a TIS framework given the intrinsic linkages between government policy and institutional infrastructures.

3 Analytical framework: Innovation systems, functions and policy

The system of innovation approach provides a resourceful vantage point for constructing an analytical framework that is instrumental in identifying the broader conditions, particularly in relation to policy, under which innovations are developed and diffused. Since the 1980s the approach has been used to identify and explain the systemic determinants of innovation and innovative performance in different countries (Lundvall, 1992; 2007) regions (Cooke, 1992; Asheim and Coenen, 2005), sectors (Breschi and Malerba, 1997; Malerba, 2005). Within this tradition, the technological innovation systems approach is most explicitly concerned with analyzing the emergence of innovations following from specific technologies (Carlsson et al., 2002; Bergek et al., 2005; Suurs, 2009).

Functions of Technological Innovation Systems

The TIS approach is particularly useful to analyze the performance of the innovation system in terms of the dynamics and activities that taking place in connection to emerging technologies (Hekkert et al., 2007; Jacobsson). To address these dynamics, key activities in the innovation system can be identified and classified along pre-defined functions of innovation systems. The functions of innovation systems approach “focuses on the most important processes that need to take place in the innovation systems to lead successfully to technology development and diffusion”. In this paper we will draw on seven functions defined by Bergek et al. (2008) and Hekkert et al. (2008). These are:

1. *Knowledge development*: The creation of knowledge lies at the heart of any innovation process. While science-based research and development are important key processes to generate new knowledge, these are not the only ones. Various other types of knowledge can also serve as input for innovation, including experience-based knowledge development through doing, using and interacting (Jensen et al., 2007).

2. *Knowledge diffusion*: For the development of new or improved products, processes or services, the diffusion of knowledge can be as important as the actual generation. Successful innovators are often those firms that know how to use ideas and knowledge of external actors (Chesbrough, 2003; Laursen and Salter, 2006).
3. *Guidance of the search* is necessary for the selection or rejection of a particular direction of technological development. The formulation of expectations and visions, priority setting in R&D strategies and foresight studies contribute to such selection processes. Also user-producer interaction provides an important feedback mechanism in this context.
4. *Entrepreneurial experimentation* implies exploring and exploiting business opportunities on the basis of new technologies and applications. It creates opportunities to learn about the functioning of new products, processes or services after exposure to market dynamics.
5. *Market formation*: Innovation is by default couched in uncertainty as it often disrupts the status quo on existing markets. The more radical an innovation is the higher its disruptiveness. This means that incremental innovation, building forth on existing products, processes or services, is more likely to be accepted by existing users and markets while markets for completely new innovations often still need to be formed.
6. *Resource mobilization*: Hekkert et al. (2007) and Bergek et al., (2007) refer to the mobilization and allocation of resources that are necessary to make the various processes in the innovation system, as described above, possible. Primarily they refer to the collective efforts to secure financial capital (seed and venture capital, policy support programs) and human capital (through education, training and competence development).
7. *Creation of legitimacy/counteract resistance to change*. Legitimacy to overcome the liability of newness (Zimmerman and Zeitz, 2002) constitutes an important but often neglected dimension of innovation. The purposeful creation of legitimacy by lobbying activities and advice activities on behalf of interest groups may be necessary in order to counteract such resistance to change.

Moreover, the system of innovation approach has an explicit and active policy agenda (Lundvall and Borrás, 2005). Whereas initial contributions were primarily geared to providing policy-makers with a framework and instruments for economic development, more recently there has been an increase in the use of the concept to improve the sustainability of various sectors, such as energy, in an economy (Coenen and Diaz Lopez, 2010; Bergek, Hekkert and Jacobsson, 2008). Previous research has demonstrated that the concept is well-equipped to carry out comparative

policy research (Asheim et al., 2003; Edquist and Hommen, 2008). Edquist (2005) even argues that a comparative dimension is indispensable as there is no such thing as an ideal or optimal innovation system. For the purpose of our analysis, a systems approach to innovation will thus be a resourceful analytical starting point to identify and analyze how different policy approaches in different countries have facilitated the upscaling and diffusion of niche innovations.

Referring to the innovation systems concept, the analytical framework applies a systemic perspective on innovation policy. This implies a broad perspective on the policy fields that need to be considered in light of how they contribute to innovation (Lundvall and Borrás, 2005). The figure below illustrates how innovation policy includes and transcends more narrowly science and technology policy, including environmental regulation (see also Porter and van de Linde, 1995). As Nauwelaers and Wintjes (2008) observe, innovation is increasingly invading the agendas of many traditional policy fields, including energy, climate and industrial policy. Apart from a development to widening innovation policy, there is a process of deepening innovation policy as new tools are added to traditional supply-side instruments such as financial support and provision of public services (Borrás, 2009). These tools include demand-side instruments such as procurement and standard-setting to promote 'lead markets' as well as intermediary instruments such as providing a platform for learning and experimenting (Smits and Kuhlman, 2004). Finally, a systemic perspective on innovation policy also opens up for multi-actor, instead of state-lead, modes of governance. While we acknowledge this, the focus of our analysis concerns government-based policy.

Innovation policy: overall innovative performance of the economy

Examples:

- Labour training and competence development
- Environmental regulation
- Corporate law

Technology policy: advancement and commercialization of sectorial technical knowledge

Examples:

- Public Procurement
- Standardization
- Technology forecasting

Science policy: production of scientific knowledge

Examples:

- publicly funded research
- tax incentives
- higher education

3. Case studies

In the following case analysis we shall apply the above framework to unpack and compare what kind of policies and policy instruments have been used in light of the emergence, development and diffusion of novel technologies in sustainable energy. Its effects are traced by looking specifically at the functions of the innovation systems.

3.1 Bioenergy and biofuels in Sweden

Introduction

Renewable energy has a prominent role in the energy system in Sweden. Due to the large share of hydropower, power production is largely CO₂ neutral. Apart from hydropower, bioenergy has emerged since the 1970s as the single most important renewable energy source. It currently stands for approximately 20% of primary energy (McCormick and Kåberger, 2005). In the transport sector, biofuels are relatively well diffused compared to most other countries in Europe making Sweden one of the few candidates to meet the EU target for 2010 of 5.75%.

An initial interest in bioenergy came in response to the oil crisis in the 1970s. Given its lack of domestic oil and gas resources, the Swedish government was keen to reduce its dependency on foreign countries on fossil fuel imports by promoting the development of domestic energy sources, including amply available biomass. This strategy of self-sufficiency created not only substantial political support for public investments in R&D and pilot plants for bioenergy but it was also actively supported and pursued as a business opportunity by the private sector. For example, since the 1970s Volvo AB actively promoted R&D for alternative fuels (Ulmanen et al., 2009). Also the pulp and paper industry, one of Sweden's most significant export sectors, has shown considerable interest in the alternative use of its biomass as an energy source as a strategy for business diversification and to open up new markets (Björheden, 2006).

Policy initiatives

For the purpose of this paper we focus primarily on the set of policy initiatives that have been taken since the 1970s and its impact on the innovation dynamics on this subsector. The empirical material is of secondary nature, i.e. based on existing case material published in Björheden, 2006;

Hillman et al., 2008; McCormick and Kåberger, 2005; Nilsson et al., 2004, Borup et al., 2008, Jacobsson, 2008, Ulmanen et al., 2009).

Existing studies point largely to the 1991 tax reform as being the most significant institutional change in the energy system that spurred the expansion of biomass in Sweden (Jacobsson, 2008 and Nilsson et al, 2004). The use of taxes on energy and carbon drastically improved the price competitiveness of biofuels in many heating applications. The carbon tax made biomass relatively less expensive than coal and oil for heating. Moreover the tax level was increased consecutively over the years. Owing to the particularities of the tax system (see Nilsson et al., 2004) biomass has been highly competitive in district-heating but not so in industry.

District heating systems have witnessed a high penetration in Sweden. They deliver approximately 50% of total heat demand in buildings. It has been quite common that municipalities own the local energy company that is responsible for production and distribution of the district heating system. As a consequence fuel choice and energy investments were predominantly a local decision (McCormick and Kåberger, 2006). In this, political considerations, besides purely commercial ones, have played a significant role (e.g. local Agenda 21 processes to promote local sustainable development¹).

The shift towards biofuels in district heating systems in the 1990s was additionally facilitated by the presence of a strong Nordic machinery and equipment sector (e.g. Kvaerner, Tampella and Ahlstrom) that has utilized its home market to introduce new technologies. Fossil fuels taxation in district heating as well as stringent emission regulation in the pulp and paper sector constituted significant business opportunities for this industry to develop new solutions for its customers.

While energy and carbon taxation created an important business opportunity for biomass entrepreneurs, there was still considerable uncertainty in terms of investment decision and long lead-times for new power capacity. In response to this, subsidies were made available for plants producing electricity from biomass. Throughout the 1990s, the Swedish Energy Agency provided total amount of 110 million euros of financial resources. Additional subsidies for investment costs

¹ Local Agenda 21 is a local-government-led, community-wide, and participatory effort to establish a comprehensive action strategy for environmental protection, economic prosperity and community well-being in the local jurisdiction or area.

were channeled to biomass fuelled plants through the Local Investment Program (LIP) for the implementation of ecological sustainability.

In terms of knowledge generation and technology development, Sweden had built up considerable competence and know-how through government research programs prior to the 1991 green tax reform. During the 1990s government R&D activities shifted more and more to near-commercial, or implementation-oriented work with particular emphasis on environmental aspects. To further strengthen the application oriented R&D activities, dedicated competence centers were established in the mid 1990s to stimulate knowledge exchange between industry and universities (e.g. around the area of combustion engineering).

More recent development have further corroborated the market formation for bioenergy in Sweden. In 2003 a tradable green certificate scheme was introduced. This scheme provides energy suppliers with a green certificate for each green MWh they provide to the grid. The users of the grid are obliged to fulfill a certain quota of green power, thereby purchasing the green certificates. This quota is raised on an annual basis. Even though demand for biomass has been stimulated through this scheme, there is still an on-going debate about its impact on the Swedish energy transition (See Jacobsson, 2008).

Similar dynamics can be observed for the emergence and diffusion of biofuels (most notably ethanol based E85). Also in this case tax reforms have spurred widespread market stimulation (Hillman et al., 2008; Ulmanen et al., 2009)). Various specific measures have been put in place to stimulate the usage of biofuels (Klitkou et al., 2008, p. 47): (1) Reduced taxation of biofuels, (2) bonus for buying a green car (including flexifuel cars), (3) exemption from congestion tax in Stockholm, (4) free parking in various cities. Another interesting regulatory measure that was taken to stimulate the adoption of biofuels has been (7) the mandatory supply of at least one renewable fuel by filling stations.

Prior to this large-scale market deployment, various local experiments had been set up to test and demonstrate biofuel-based municipal public transport systems. These demonstration projects often involved fuel companies, automobile manufacturers, local public transport authorities. Later experiments also involved non-fleet vehicles. As studies by Hillman et al., (2008) and Ulmanen et al. (2009) have shown, these small scale experiments paved the way for the subsequent market roll-out. Partnerships between various stakeholders (fuel companies, automobile manufacturers as

well as national and local authorities) had been established which had largely similar expectations about biofuels. More importantly these studies illustrate very well how these local, multi-stakeholder experiments facilitated the introduction of subsequent tax-exemptions and other regulatory measures. For example, the established partnerships provide for the political momentum necessary to allow for stakeholders to influence the decision-making process (e.g. through extensive lobbying). Also, the experiments have disclosed which bottlenecks exist for the wider adoption of green vehicles and biofuels (e.g. supply of biofuels at filling stations).

Analysis

The case clearly points to the early introduction of energy and carbon taxes as a watershed in the diffusion of bioenergy in Sweden. It allowed for biomass to become price-competitive with fossil fuels. As such, it created a positive effect in the innovation system as it created market pull for biomass application in district heating system in Sweden and provided an important incentive for entrepreneurial experimentation for the related machinery and equipment sector. The financial advantage created by energy and carbon taxes was further corroborated by capital investment subsidies for plants that are producing electricity from biomass. In this context it should be noted that the district heating system constituted a relatively large share for total heat production in buildings, which is a particularity in the Swedish energy innovation system. Similarly, the significance of the machinery and equipment sector for biomass relates to a particular feature of the Swedish innovation system. The market creation dynamic initiated by the 1991 tax reform has further evolved through the introduction of a tradable green certificate in 2003. This is another example of a market-oriented regulatory approach to stimulate diffusion of renewable energy in Sweden. In terms of effects on the innovation system, these economically oriented policy initiatives have helped new actors to enter (notably district heating and the machinery and equipment sector) and to contribute to the adoption and diffusion of biomass based energy production.

A similar dynamic holds for the emergence of biofuels, emphasizing market creation through the introduction of financial (dis)incentives. However, in this case, the prior set-up of local experiments should also be stressed as a critical policy initiative. They not only allowed for the formation of advocacy coalition in the innovation system but also generated knowledge about the socio-economic conditions for the wider adoption of green vehicles and biofuels.

3.2 Wind power in Denmark

Introduction

No other country has such a high share of wind power in its total electricity production than Denmark. In recent years it constitutes 16-19% of total domestic production (Borup et al., 2008). However, not only is Danish wind power considered a success story in terms of greening the energy system, it is also seen as a remarkable success in terms of industrial policy. Danish producers of wind power technology have a share of around 1/3 in the global market. As such, wind power obtained the role as one of the largest export areas for Denmark and provides an important source of employment growth in the last decades. Around 23.500 people are employed in the area in 2008. It is probably fair to say that the industry constitutes a mature industrial cluster that is firmly embedded in the Danish energy system and provides a serious challenge to the fossil fuel regime.

Policy initiatives

The Danish government has played an active and supportive role in the build-up of the wind energy cluster. Having its roots in the energy crises of the seventies, the Danish government pinpointed wind energy as a viable alternative to diversify and secure national control over the domestic energy system. Moreover, Denmark was, compared to Sweden and Finland, far less interested in nuclear power set off by the incidents at Three Mile Island (US) and Chernobyl. In the eighties and nineties, support for wind technology through energy policy was galvanized by industrial policy. The emerging industrial build-up around wind energy was increasingly seen as a growth pole for the national economy which suffered from an economic crisis and high unemployment.

The success of the Danish wind industry is to a large extent based on its first-mover advantage. The origins of the modern wind turbine can be traced back to a design developed by a Danish engineer / inventor in the 1950s (Bruun). This design lies still at the basis of the turbine design employed by the global industry leader, Vestas. By 1980, besides Vestas, there were nine other Danish wind turbine firms, with the top three holding 63% of the Danish market (Karnøe, 1991). Over time the dominance of Danish firms on the domestic market has only increased reaching up

to 99% of installed turbines made by domestic companies in 2004 (Lewis and Wiser, 2007). Based on a global study of the industry the authors have shown that wind turbine manufacturers usually get their start in their home country markets; a trend that is clear in the largest markets of Denmark, Germany, Spain, the US, and India, as well as some of the smaller, emerging markets.

Even though the degree of rational policy foresight and planning should not be overestimated, policy support to the emerging wind industry is considered an unprecedented success in the history of Danish technology and industrial policy. Karnøe and Buchhorn (2008) distinguish a number of concrete elements in Danish policy: (1) Active stimulation of market development by investment subsidies and production grants (2) regulation of actors rights and responsibilities to own grid-connected wind turbines and sell electricity to utilities (3) financial subsidies to support industry with testing, demonstration and R&D in different forms and (4) consistent, long-term political commitment that is made sufficiently hard through measurable targets.

An active stimulation of market development was one of the hallmark policies of the newly established Danish Ministry of Energy at the end of the 1970s. The second energy crisis of 1979 provided a timely political rationale to introduce a substantial 30% investment subsidy for buyers of certified wind turbines. Despite these financial benefits, wind power installations in the Danish home market remained small. To stimulate the home market, subsidies were raised to 50%. This level of subsidy was more successful. Total windpower capacity quadrupled between 1984 and 1985. These direct investment subsidies were gradually reduced and basically faded out in 1989 (Garud and Karnøe, 2003). A more controversial policy measure that was put in place concerns favorable customs duties (Lewis and Wiser, 2007). This refers to customs duties that support local turbine manufacturing by favoring the import of components over full turbines. However, this measure can be seen as a trade barrier and, thus, considered illegal under WTO trade agreements.

In addition, Denmark was the first country to couple aggressive quality certification and standardization programs with provision of subsidies and is still a world leader in this field. For this purpose the establishment of the Danish Wind Turbine Test Station in 1978 was key. Its initial mission was to provide technical support to the emerging industry. Soon after the test station was established, the Danish government passed a law that required that wind turbines are tested and certified before owners could qualify for public subsidies. As a result of this strategic position the test station became an important knowledge resource for industry and arena for

communication and information exchange (Garud and Karnøe, 2003). The test centre was also an important member of the 'contact-group-meetings' which, in addition, comprised of the Wind Mill Owners' Association, the Organization for Renewable Energy, involved Ministries and Electric Utilities. According to Garud and Karnøe (2003), this contact group served as "an important forum for co-shaping policies governing the emerging technological path" (p. 290).

While R&D funding has been allocated to wind turbine technology development by generally any country with an industrial base in wind power, Denmark's R&D budget, although relatively small in magnitude, is considered to have been allocated more effectively among smaller wind companies developing varied sizes and designs of turbines in the initial years of industry development (Kamp, 2002). It is important to note that, contrary to the more R&D intensive US wind industry, the Danish firms are characterized by a so-called 'bricolage' style of innovation, referring to the incremental, experimental and improvisational style of learning and engineering product and process improvements (Garud and Karnøe, 2003). This is also related to the dominance of SMEs that constituted large networks of specialized suppliers, sub-suppliers and manufacturers. In fact, the industry represents a textbook example of a dynamic cluster in which cooperation and competition coexist in a fruitful way fostering innovation on a collective level. This industrial structure provided the backdrop for a complex and expanding knowledge and competence base drawing on flexible specialization and user-producer learning.

Witnessing its political commitment to sustainable wind energy, Denmark has a history of stable and profitable feed-in tariff policies to promote wind power development. Wind turbine owners were refunded a new fossil fuel energy tax for each kWh of electricity generated by wind power. Moreover, buckling under political pressure, the utilities agreed to pay owner-users for wind power at a rate of 70–85% of the prices they could command for power distributed through their grid.

Analysis

What characterizes the Danish case of wind power is the congruence of environmental and industrial policy. This has resulted in a poignant mix of technology push and market pull measures that continuously have stimulated innovation, diffusion and adaptation in this emergent industry. The test centre, initially established with modest resources, has played a critical (yet probably unintended) role in this combinatory approach. It served as the central institution that tested wind turbines before owners could receive a subsidy while at the same time acting as a technical support centre for the industry. Meanwhile it was also involved in an important multi-

stakeholder windpower platform that facilitated information and knowledge exchange. Being an actor that has been brought into the Danish windpower innovation system through public policy intervention, the centre provided what could be labeled as systemic support to the industry. In terms of policy rationales, the centre can be seen as part of a multi-dimensional policy framework cutting across various policy activities (i.e. regulative, supportive, informative). The combination of certification, subsidies and multi-stakeholder dialogue creates powerful complementarities in the innovation system. As such, policy has had a positive influence on market creation and resource mobilization (through subsidies), knowledge generation and diffusion as well as guiding the direction of search (in creating a 'centre of excellence') as well as creating an advocacy coalition (through the contact-group-meetings).

3.3 The Case of Dutch Biofuels

Introduction

In the Netherlands, contrary to Sweden and Denmark, the diffusion of renewables has barely taken off. In 2009 the share of renewable energy use made up 3.8% of primary energy (CBS, 2010). Most of this comes from the production of electricity from biomass cogeneration and from wind turbines. A small share comes from the use of biofuels in transport (3.4 % of total fuel consumption) (CBS, 2010). The idea of using biofuels has emerged in the 1990s against the background of a declining agricultural sector. The production of non-food crops held the potential to help the sector to diversify and connect with new markets. However, ever since the emergence of biofuels, the Dutch national government has taken a reluctant position towards its environmental benefits. Not surprisingly, the main actors driving the development of biofuels in the Netherlands have been entrepreneurs and local governments pushing the central government to support research, experimentation, infrastructures, markets, etcetera.

Policy initiatives

In 1990-1997 various local initiatives start adopting biofuels, mainly in the domain of public transport. The province of Friesland became involved in biodiesel experiments together with boat rental companies. An important reason is the increase of regulative pressure with respect to surface water quality. Biodiesel is biodegradable and thus poses only a limited threat to the water quality. These experiments received a full tax exemption from the national Ministry of Finance which was however stopped in 2000. After intensive lobbying by the province, the exemption was continued again in 2003 (van der Laak et al., 2007). Also other local initiatives were set up

during this period, e.g. the region of Groningen and the city of Rotterdam public transport companies started a trial with bioethanol in buses.

A number of actors is involved, among which the alcohol producer Nedalco and Novamont. Funding for the experiments is provided by the companies themselves and through European subsidies. These are the first signs of biofuel adoption taking shape. Technically, the outcomes of the experiments are a success but economically biofuels cannot compete with fossil fuels. Measures of national support are absent. This relates to the emergence of a controversy around the use of biofuels. The national government agency for energy and environment (Novem) states that implementation of biofuels is too expensive compared with co-firing biomass in power plants. This sets the tone for a 'debate' that goes on until today. Regional actors emphasise the strategic and environmental value, whereas scientists and environmentalists stress the meagre performance of biofuels. The national government stands divided on the issue and refrains from taking any clear action.

Influenced by the Kyoto treaty Novem initiates in 1998 a national programme for the assessment and support of gaseous and liquid CO₂-neutral energy carriers: the GAVE² programme. In 1999, GAVE's first move is to authorise a number of assessment studies, aimed at resolving the controversy around various biofuel options. Their advice is to exclusively support fuels which promise a CO₂ reduction of at least 80% (i.e. second generation biofuels). Consequently, all first generation options are (de facto) excluded from further assessments. Moreover the assessment studies designate that biofuel production has the potential to become economically feasible, provided that production scales are sufficiently high. These studies had a major impact on the guidance of search for biofuel development in the Netherlands. From 2001 to 2002, GAVE establishes a subsidy scheme in order to support demonstration-scale pilot plants. The scheme consists of two tenders for a total budget of approximately 2 million Euros. Two experiments focusing on combining biomass gasification with Fischer-Tropsch synthesis, are considered most promising (Ulmanen et al., 2009). If successful, they would enable the production of biodiesel from practically any biomass source. The projects are set up by two networks - the Shell-ECN³ network and the TNO-Nuon network – as well as various other actors, such as banks and a car company. The projects are successful with respect to solving technological bottlenecks related to cleaning the synthesis gas that is required for the Fischer-Tropsch process. Setting up a

² GASvormige en Vloeibare klimaatneutrale Energiedragers

³ The Dutch energy research institute

commercially viable plant, however, appeared to be unfeasible due to insufficient financial support, not the least from public funds (Suurs and Hekkert, 2005).

The 2003 EU Biofuels Directive forced the Dutch government, despite its resistance, to design an implementation plan. As GAVEs subsidy scheme had stopped, a reorientation of policy was needed. Moreover, the EU Directive coerced Dutch policy to reconsider first generation biofuels in spite of its earlier orientation towards second generation biofuels. Initially, ad-hoc tax reductions are issued to an increasing number of local biofuel experiments across the country. As a more general response to the EU Directive, the Dutch government introduces a general tax exemption in 2006, followed by a scheme of obligatory blending in 2007. The scheme obliges oil companies to sell biofuels in an increasing share of their fossil-derived fuel sales; from 2% (on an energy basis) in 2007 to 5.75% in 2010. As a result of these policies business interest and entrepreneurial experimentation increases with e.g. first generation biofuel plants and logistics facilities being built in the port of Rotterdam. In addition, a 60 million Euros subsidy programme is initiated specifically directed at 2G biofuels demonstration pilots for the period 2006-2014 as part of the Energy Transition Program. However, the biofuels controversy still rages on, undermining the long-term perspective for all biofuels development. The controversy is becoming stronger as studies show that the increased land use for energy crops result in rising food prices and in the cutting of vulnerable nature areas like rainforests.

Analysis

The case of Dutch biofuel developments is characterized by a rather unstable and frequently shifting policy framework. Positive policy impulses on the adoption of biofuels have in fact primarily originated from the regional and the European level. Dutch national policy has been largely subject to an indecisive position vis-à-vis the environmental, social as well as economic sustainability of biofuels. At the same time, local and regional governments got involved with various firms to set up real trials to try out the usage of biofuels in practice. These initiatives paved the way not only for the creation of various advocacy coalitions but also gave scope for entrepreneurial experimentation. The economic and structural impact of these initiatives remained however limited due to a hampering creation of markets for biofuels. A similar observation can be made for the economic support provided by the GAVE program to develop pilot plants and, subsequently, to scale these up to commercial usage. Firms decided to discontinue their development projects due to insufficient market potential and failing financial support from public funds. Again, the primary bottle-neck can be traced to the (low) performance of the

innovation support structure to stimulate demand for biofuels. It was not until the Dutch government was forced to implement regulation in order to comply with the EU Biofuels Directive that an effective incentive was provided for firms to engage on a commercial basis with biofuels. In sum it can be argued that much of the national Dutch biofuel policy primarily has been geared to pushing technologically more advanced second generation biofuels. Even though important networks/coalitions have been formed through local experiments and considerable economic support is provided for knowledge generation and diffusion, the main bottleneck for a well-functioning innovation system remains largely unaddressed, i.e. lack of market pull.

4. Conclusions

In this paper we have investigated the effectiveness of various policy instruments in supporting the scaling up process of niche technologies in the area of sustainable energy. To assess the impact of these policies we have drawn on the functional approach to technological innovation systems. This allowed us to specify what particular performance dimensions of the innovation system were influenced by which policies. Empirically three cases were investigated, bioenergy and biofuels in Sweden, windpower in Denmark and biofuels in the Netherlands. The tables below provide a stylized overview of the main findings of these case studies. By way of conclusion we shall now conduct a comparison across these cases and arrive at policy lessons.

The two success cases (Sweden and Denmark) show that an important precondition for upscaling of niche technologies to take place resolves around the creation of markets. However, such market creation was not pursued as a rational and purposeful vision by government to support new technology but came about in a rather indirect way. In both countries, government as well as industry attention and interest for renewable energy was borne out of a concern for energy security, following the energy crises in the 1970s. Moreover, both governments saw opportunities to support domestic industry in terms of openings up new markets. Later on, concern for climate change further strengthened the ambition to increase the level of renewable energy. This points to a mix of different policy goals. Emerging niche technologies were supported through a combination of concern for energy security (energy policy), decarbonizing the energy system (climate policy) and supporting domestic industry (industry policy).

Secondly, the Danish and Swedish case show that a mix of economic and administrative instruments can be effectively employed to create market demand for sustainable energy and induce entrepreneurial experimentation. Green taxes, emissions regulations, tradable certificates,

standardization, free parking have provided important incentives for firms to experiment on a commercial basis with new technology. Both Sweden and Denmark have provided such incentives at an early point in the development trajectory of a technology. Even though the Dutch government did provide economic incentives for entrepreneurial experimentation and commercialization as well, these support schemes were often on an ad-hoc basis creating considerable uncertainty for entrepreneurs and investors. Setting-up societal experiments has also played a supportive role in the adoption of emerging niche technology in terms of knowledge generation & diffusion (know-how) as well as the creation of multi-stakeholder advocacy coalitions. As such, the case studies support the claims made in the literature on strategic niche management and transitions experiments. However, such deliberative experimentations seems to create necessary but not sufficient conditions for scaling up of niche technologies. The nature of such instruments is highly voluntary and requires complementary support through economic and administrative policy measures. This emphasizes the use of transition experiments in the context of a policy mix of other policy instruments. As a stand-alone, there is a risk that such experiments have too little leverage to induce change (for a similar argument in light of the Dutch Energy Transition Program see also Kern and Smith, 2008).

Finally, in all cases we find that the national level is not the only nor the most important level to design and implement for supporting emerging niche technologies. The Dutch case showed how in the context of weak support on the national level, both local and supra-national policy created at least some momentum. At the same time, there was little positive interaction between the various levels of policy support (it would probably more justified to talk about tensions between the different policy levels). The Swedish case provides some evidence of the positive complementarities that can be achieved in terms of a multi-level policy mix. Here local experiments and trials created synergy effects with a stringent national regulatory framework in terms of creating advocacy coalitions for emerging niche technologies.

Policy	Functional impact
1991: energy tax reform	Market creation Entrepreneurial experimentation
1990s: plant investment subsidies	Market creation Entrepreneurial experimentation
1990s: public research	Knowledge generation & diffusion

programs	
1990s: local experiments	Knowledge generation & diffusion Advocacy coalition
2000s: tradable green certificates, tax benefits biofuels & biofuel obligation	Market creation Entrepreneurial experimentation

Bioenergy and biofuels in Sweden

1980s: investment subsidies, production grants (feed-in tariffs) & favourable customs duties	Market creation Entrepreneurial experimentation
1980s: quality certification & standardization (incl. Establishment of Danish Wind Turbine Test Station)	Market creation Entrepreneurial experimentation Knowledge diffusion & generation
1980s: contact-group-meetings	Knowledge generation & diffusion Advocacy coalition

Windpower in Denmark

1990-1997: local experiments with adhoc financial support	Entrepreneurial experimentation Advocacy coalition
1998-2002: public research programs specific for 2G biofuels	Knowledge generation & diffusion Guidance of the search
2003-2006s: generic tax benefits for biofuels	Entrepreneurial experimentation
2007 – biofuels obligation	Market creation Entrepreneurial experimentation

Biofuels in the Netherlands

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