INTERNATIONAL JOURNAL OF

ENVIRONMENTAL TECHNOLOGY AND MANAGEMENT

Volume 9, Nos. 2/3, 2008

Editor-in-Chief: Dr. M. A. Dorgham

Web site: www.inderscience.com

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ISSN (Print) 1466-2132
ISSN (Online) 1741-511X

Published and typeset in the UK by Inderscience Enterprises Ltd

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TRANSFORMING ENERGY SYSTEMS TOWARDS SUSTAINABILITY: CRITICAL ISSUES FROM A SOCIO-TECHNICAL PERSPECTIVE

Guest Editor:

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Editorial

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Energy provision, distribution and consumption with its effects on social welfare, environment, climate change and resource exploitation is certainly a crucial field for a transition of our economies towards sustainability. Much of the discussion about energy systems is focussing on 'technical' issues such as the availability of alternative resources and technologies.

However, it is both the technological basis and the institutional framework of energy systems which are presently in a state of flux. While energy markets are increasingly liberalised and, at the same time, new and often decentral energy technologies are introduced, the role of various actors involved, such as users or service providers, is in a process of change, too. With new energy service concepts, the provision of energy can be customised to the specific needs and wants of users instead of just supplying a standardised product (including possible adverse effects of a social differentiation of service). Similarly, the implementation of decentral energy generation technologies changes the way energy systems are managed and may lead to an entrance of a range of new actors into the system.

What we observe thus is not only the improvement of a technical system of energy provision but a whole socio-technical configuration in a process of transformation. Many of these new technical and organisational changes also imply innovations at system level. The ensuing requirements of system adaptation are not possible without comprehensive social learning processes.

The transformation of socio-technical systems, such as the energy system, hence is a complex process taking place at different levels (new technologies, new social practices at a micro-level of niches; new regulations, norms and actor-configurations at the level of socio-technical systems or regimes), and involves a broad range of actors with their specific interests and expectations. Implementing policies to direct this transformation towards more sustainable configurations of technologies, social practices and institutional regulations cannot take place in a purely top-down manner, but has to involve a broad basis of social groups and stakeholders and has to be organised in a reflexive way that is flexible enough to adapt to changing contexts and societal goals.

This special issue explores the potential of interdisciplinary socio-technical analysis to better understand the transformation of energy systems as a co-evolution of changes at the level of technologies, institutions, social practices and actor constellations, and to inform governance strategies to shape the transformation of socio-technical systems towards sustainability. The contributions of this issue are dealing with various key aspects of the transformation of energy systems such as:

- system innovations in the transformation of energy systems
- governance of transition processes towards sustainability
- the changing role of energy consumers
- socio-technical analysis of the introduction of new energy technologies
- assessing institutional innovations and new regulatory instruments in the energy sector
- improving social learning processes in the system of energy provision and consumption.

The paper by Rohracher gives an introduction to some of the key issues and concepts covered by a social science–based analysis of energy system transformation – the analysis of socio-technical arrangements and their dynamics of change, the importance of the projective dimension of expectations, visions and scenarios, and the contributions such a socio-technical analysis can make to the design and support of a long-term oriented, adaptive and reflexive energy and technology policy.

Most of the papers of this special issue focus on a specific sub-sector of the energy system or the development and diffusion of specific energy technologies. However, the empirical analysis is never restricted to these technologies, but emphasises their social embeddedness, the importance of institutional frameworks, broader socio-cultural developments and changing actor constellations. An example is Bunting's analysis of the specific characteristics of the diffusion of wind power in Australia – a development path that is influenced by the interrelations of technological characteristics with the institutional structure of the electricity sector and the interpretations and socio-political visions of influential stakeholders. Other technologies with a potential to transform the energy system such as the capture and storage of carbon dioxide (CCS), as analysed by Fischer and Praetorius, or the combined generation of heat and electricity at household level (micro-CHP), as investigated by Sauter, are at an earlier stage of development than the use of wind energy. Both papers are a good example of how socio-technical analysis can improve our understanding of the current state and the challenges faced by emerging fields of technology. These challenges often lie in the diverging strategies and interests of actor groups, mismatches with the existing institutional framework and the way policies and regulations try to deal with these emerging technologies.

An important issue covered by several papers in this issue is the role of users for the market introduction of new energy technologies. Crosbie and Guy investigate consumption practices of compact fluorescent lamps and link the formation of these practices to the social habits and practices of household lighting and the way they are portrayed in the media. Fischer, in turn, looks at the pioneer users of fuel cell–based combined heat and power generation, the characteristics of this social group and the way they might be more effectively involved in the further development of this technology. Both papers show how users and use practices – even if they play an active role in technology development – are themselves 'configured' and guided by broader social contexts. This is also what Chappells works out convincingly in her paper demonstrating the complex socio-technical interdependencies of energy supply and demand. The close coupling of structures of provision and consumption calls for new approaches to a more systematic management of demand.

The remaining two papers of this issue analyse the systems of innovation around specific energy technologies. Kamp compares the introduction of wind power in the Netherlands and Denmark, and explains the differing success of these technologies in the two countries by the different fulfilment of various innovation system functions such as market formation or entrepreneurial activities. Loorbach, van der Brugge and Taanman widen the innovation system perspective to the whole energy system and evaluate the Dutch policy to support the transition of the energy system towards sustainability against the backdrop of an operational framework for complexity-based governance, which they develop based on socio-technical concepts.

Summing up, the special issue covers a broad range of socio-technical approaches to better understand the current transformation of energy systems and to feed back this understanding into improved strategies of policymaking. The contributions hopefully draw more attention to the relevance of social science research (social studies of technology in particular) for developing strategies to make energy systems more sustainable and to face the challenges of climate change.

Energy systems in transition: contributions from social sciences

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Abstract: The aim of this paper is to discuss the potential role of social sciences – especially social studies of technology and innovation studies – for our understanding of energy provision and consumption. Energy systems are best understood as socio-technical arrangements with a strong interrelation of technological and social elements such as institutions, regulations, cultural values, social practices as well as interests, expectations and relationships of the actors involved. Such a perspective also gives us a better grasp of the ongoing dynamics of energy system transformation and stimulates new approaches to the governance of transition processes towards sustainability. Contributions of social sciences can support the understanding and shaping of energy transitions in an analytic, projective and reflexive dimension.

Keywords: energy systems; governance; scenario-building; social study of technology; socio-technical experiments; socio-technical systems; sustainability; transition management.

Reference to this paper should be made as follows: Rohracher, H. (2008) ‘Energy systems in transition: contributions from social sciences’, *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.144–161.

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1 Transformation of the energy system and the perspective of social science research

For decades, energy generation has been dominated by a regime of centralised, state-owned monopolies producing electricity and heat mainly based on fossil fuels. Since the energy crises of the 1970s and 1980s, this post-war regime has come under pressure from various directions and is currently undergoing a process of transformation. Whether this process will lead to a more sustainable energy system is an open question. This paper deals with the possible contribution of social science research to a better understanding of the energy system as a 'socio-technical system in transformation', and with the guidance such an analysis can provide to policy-making and to improving social learning processes and efforts to make the energy systems more sustainable.

We can identify three main sources where the current drivers of change for the energy system reside:

1 The energy regime is confronted with the requirement to reduce its negative impacts on the environment and climate. Energy consumption has turned out to be one of the main sources of greenhouse gas emissions and thus of climate change (IPCC, 2007). With a growing public and political awareness of the urgent need to mitigate climate change, the aim to increase energy efficiency and the use of renewable energy sources have been moving higher up on the political agenda. Both issues are a challenge for the current energy system: energy efficiency with a need to put more emphasis on the demand side of the electricity system as opposed to the supply-side dominated view of the incumbent energy regime; and the introduction of renewable energies with its better compatibility with decentralised and distributed energy generation in contrast to the 'bigger is better' view of traditional utilities.

2 Along with the need to make energy systems more environmentally sustainable, we have witnessed remarkable changes at the level of the institutional framework and governance of energy systems. The 'liberalisation' of infrastructure systems has become a worldwide trend and mirrors, as Renate Mayntz, 1993, p.107, points out, both structural changes of modern societies ('from hierarchies to networks') and political–ideological motivations ('neo-liberalism'). Privatisation of formerly state-owned utilities, re-regulation to introduce market-like structures into formerly 'natural monopolies' and additional regulatory changes led to a profound transformation of institutional structures and power relationships within the energy system and with respect to its governance and public control. Within the European Union, this process of market liberalisation has been driven by the aim of a common European energy market and the aim to deliver energy more efficiently in a competitive environment. However, the effects of this new regulatory regime are highly disputed – some authors argue that most of the promises of liberalisation have not been delivered and the rhetoric of liberalisation that remains is no more than the 'Grin of the Cheshire Cat' (Thomas, 2006, p.1975; see also Ringel, 2003).

3 Change has not been restricted to environmental pressure and institutional reorganisation. During the past decades, we have also experienced a shift in the technological base of energy systems – partly as a cause and partly as an effect of transformations at the institutional level. New technologies for electricity generation, such as Combined-Cycle Gas Turbines (CCGT),[1] combined heat and power

production at small scales (even at household level) (see, for e.g., Marwell and McInerney, 2005; Pehnt et al., 2006)[2] and various renewable energy–based electricity generation technologies (e.g. biomass, biogas, photovoltaics), have often reversed the benefits of scale in the electricity generation industry and have been becoming more cost-efficient (Diesendorf, 1996, p.36). Such developments weaken the argument for natural monopolies and favour the market entrance of new producers as well as a more decentralised organisation of the electricity system. At the same time, the rapid introduction of Information and Communication Technologies (ICT) has remarkably increased the capacity to manage a more horizontally organised and active electricity network, with a variety of independent generators, more intermittent energy sources such as wind energy and electricity prices at least partly built on spot markets.[3] Moreover, ICT have opened various opportunities to offer value-added services and integrate electricity customers as active participants in the energy system (e.g. managing electricity loads at household level or even supplying electricity from micro-generation facilities) (cf. Guy and Marvin, 1998).

Although it is obvious that the energy system is currently in a state of transformation due to the changes already implemented and still ongoing in different domains, it is far from clear where these changes will lead in the longer term. On one hand, there is a chance of a radical system transformation characterised by new actor configurations (e.g. a significant proportion of independent producers, new intermediary organisations, users as co-producers of energy services), institutional contexts and generation technologies (e.g. low proportion of fossil fuels as energy carrier, distributed generation). Many of the technological and organisational changes we are experiencing may induce (and also require) changes at a system level and may lead to a radically changed system of energy generation and consumption. On the other hand, there is definitely a possibility that new technologies and regulatory intentions are being integrated into the traditional institutional structure of the electricity sector (centralised organisation, few dominant players, large-scale generation) and merely lead to incremental changes.

With the aim of sustainable development in mind, we thus have to ask: How can we develop strategies to consciously influence the transformation process of energy systems and ‘push’ it towards a more sustainable pathway? As a prerequisite for such strategies, we need a thorough understanding of the system of energy generation and consumption and of its dynamics of change. The short introduction to the different drivers of energy system transformation processes should already have made clear that such an understanding cannot be limited to the technical network alone but has to conceptualise the energy system as a socio-technical system where technical developments and characteristics cannot be separated from institutional structures and the values, interests and social practices of the participating individuals and organisations. Such a broad understanding may, in consequence, be functional to find levers to shape the transformation process with respect to socially desirable pathways.

Understanding the socio-technical dimensions of energy system transformation and sketching out the strategies to shape this process are the main desideratum of this paper – and in fact of this whole special issue. In this introductory contribution, the author will specifically discuss the contributions of social science research to our current understanding of socio-technical transformation processes.

This paper will argue that societal strategies, in general, and energy policy, in particular, aiming at a long-term transition of our current energy system towards increased sustainability may profit from social sciences in various ways – not only by getting a better grasp of the internal dynamics of innovation and system transformation processes but also by contextualising this transformation in broader socio-economic trends and by suggesting strategies for a long-term, adaptive and reflexive policy.

The author has structured the following discussion of social science contributions into three sections, which correspond to the different roles that social science research might play in dealing with the transformation of energy systems. At an analytical level, social sciences may improve our understanding of energy generation, distribution and consumption as a socio-technical configuration. In this way, social sciences may be functional in improving our non-technical knowledge about various energy options, e.g. the increased use of renewable energies, radical decentralisation, the 'hydrogen economy' or a significant reduction of energy demand. In the second section, we will have a closer look at the 'projective dimension' of the change of energy systems, i.e. the roles that expectations and visions play in innovations and system transformation and how these visions can be dealt with strategically. The strategic use of visions and projections into the future in scenario development techniques and foresight strategies leads to the third area of social science contributions: the understanding and facilitation of social learning processes and the support of governance strategies by introducing a reflexive dimension into the shaping of socio-technical system transformations. This section will deal with the strategies and instruments inspired by social science approaches, such as transition management, socio-technical experiments or Strategic Niche Management (SNM).

2 Analysing socio-technical systems

Social sciences have already gained a sophisticated understanding of the interdependent processes of social and technical change. Energy systems are socio-technical configurations where technologies, institutional arrangements (e.g. regulation, norms), social practices and actor constellations (such as user–producer relations and interactions, intermediary organisations, public authorities) mutually depend on each other, and are embedded into broader contexts of cultural values, socio-economic trends (globalisation, individualisation, etc.). Innovation processes are becoming increasingly complex, and are an outcome of the interaction between a multitude of actors, distributed over many different institutions and locations. This also means that while a central steering of such transformation processes becomes increasingly difficult, processes of social learning, coordination and socio-technical experimentation gain importance.

Nevertheless, there are various 'conceptual lenses' to analyse socio-technical change and organise the 'seamless web' of social and technological elements. The focus and the unit of analysis very much depend on the specific dimensions of socio-technical change in energy generation and consumption we want to understand – whether it is rather the stability of existing technical and institutional arrangements and the possibilities of a discontinuous shift to a new stable state, whether it is the dissemination and social embedding of specific energy technologies and the formation of networks and markets along with this process, or whether it is the dynamics of energy consumption and adoption of new products and technologies. This section will sketch some of these analytic approaches of social sciences, which may help to better grasp the socio-technical transformation processes and their interaction with broader social and economic structures.

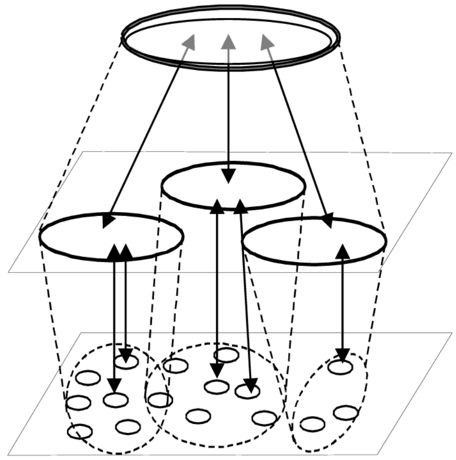
The multi-level model of innovation is well suited to analyse the interrelation of stability and dynamics of socio-technical change and historic shifts between dominant modes of the organisation and orientation of socio-technical systems (see e.g. Rip and Kemp, 1998; Geels, 2004). At the core of this approach is an evolutionary concept of variation at the micro-level (niches, new technologies, products) and selection at a meso- or macro-level (dominant socio-technical regimes), though, in contrast to its biological counterpart of variation-selection, the 'overthrowing' of selection environments by variation processes (regime shifts) is possible and an important explanandum of the concept. Moreover, the multi-level model is founded on an understanding of different (and separable) temporal dimensions of change – from short-term processes at a micro-level to the 'long duree' of changes at the macro-level of socio-technical landscapes.

In more concrete terms, the multi-level model of technological change separates the 'breeding' of new technologies into confined technological niches from a meso-level of socio-technical regimes (e.g. the system of mobility) and a broader context of the socio-technical landscape, which encompasses cultural norms, values or dominant economic or governance regimes (such as the present trend to liberalise former infrastructure monopolies). The central element in this concept is the meso-level of the 'socio-technical regime', which refers to the temporal stability of socio-technical configurations and means a rule set or grammar that structures the socio-technical co-evolution process. The regime level incorporates the mutually reinforcing technological and institutional structures of specific domains such as the energy system, and is characterised by a resistance to change (which, for example, may cause promising new technologies to fail). The activities within the energy regimes are coordinated through various rules – not only at a regulative level but also by cognitive (paradigms, cognitive frames) and normative (values, expectations) rule sets (Geels, 2004). The way such a regime evolves "is structured by the accumulated knowledge, engineering practices, value of past investments, interests of firms, established product requirements and meanings, intra- and interorganisational relationships [and] government policies" (Kemp, Rip and Schot, 2001, p.273). Nevertheless, under specific circumstances, regimes may shift into new semi-stable states, especially if radical innovations (technological and/or institutional) coincide with strong outside pressures on the regime.

The creation of novel technologies thus is shaped by the interactions of the micro-level of users, firms and households, the meso-level of technological regimes and the macro-level of socio-technical landscapes. The value of such a concept is to point to the multi-dimensionality of processes of socio-technical change, to the multiplicity of actors involved in the process and to the embeddedness of local practices and niches in various contexts with their own specific history and dynamics. The regime perspective is helpful for thinking about the energy system transformations in terms of the stability of existing configurations, in terms of the various social and technical elements that have to come together to cause a regime shift and, not least, in terms of the integrated and long-term policy strategies needed to shape such regime shifts.

Figure 1 tries to capture this embeddedness and the co-evolution of socio-technical elements such as artefacts, practices and meanings at different levels of integration. Many strategies of environmental policy such as regulation and standards are focusing on the regime level – but are highly dependent, as Figure 1 indicates, both on broader socio-economic structures and on practices, expectations and strategies of actors at the micro-level.

Figure 1 A multi-level model of innovation



Source: Rotmans et al. (2001).

A thorough analysis of the meso-level of dominant socio-technical regimes may thus crucially contribute to understanding the dynamics of energy system transformation (why do certain technologies and strategies fail?) and to designing more appropriate energy policies that more coherently focus on technological and institutional levels as well as on changing social practices and other framework conditions (see e.g. Schenk, Moll and Schoot Uiterkamp, 2007). A number of socio-technical analyses contributing to our understanding of energy system transformation have already been carried out. Verbong and Geels (2007), for example, historically analyse the evolution and change of the electricity regime in the Netherlands and look for the drivers and conditions of a far-reaching integration of renewable energy sources. The interactions they found between the existing regime with the dynamics of niche development in the biomass, wind or photovoltaic sector prompted them to be cautious about the radicality of the impacts of these technologies on the existing regime. We are currently witnessing environmental adjustments of a regime still driven more by liberalisation and Europeanisation than by environmental concerns (p.1036). With a similar perspective on electricity system transformation, Raven (2006) investigates the interrelations of the developing niche of biomass co-firing in coal plants (which exhibits its own internal dynamics and stability) with the dominant electricity regime (which – e.g. in the course of liberalisation – is also characterised by different levels of stability). Sketching the 'innovation journey' of such an emergent technology against the backdrop of niche and regime dynamics provides a basis to assess the development potential of this innovation and to advise strategies to improve the niche formation process.

However, there still are a number of aspects of the multi-level model of innovation to be cautious about. In general, the picture is more complex than the niche-regime-landscape picture suggests. On one hand, regimes are linked in various ways to other socio-technical regimes – the potential of biomass use, for example, depends on agricultural and forestry regimes (e.g. competing land uses; use of wood for non-energy purposes), waste management, etc. at least as much as on the energy regime, and can often only be analysed in a comprehensive perspective. Similarly, the separation of niches and regimes is not always clear-cut. Even if there is a dominant regime, e.g. of centralised, fossil-fuel-based electricity generation, there can be remarkably stable sub-systems, e.g. around wind energy or biogas, which can be seen as a kind of niche-regime or different levels of aggregation (Geels and Raven, 2006). The regime notion thus tends to suggest more coherence and homogeneity in the organisation of socio-technical systems than one empirically finds in the 'real world'. In the end, the regime notion is thus rather vague and gives no clear indication on external (regime-environment) and internal (regime-niche) boundaries. This ambiguity moreover makes it difficult to conceptualise the impact niches have on regime shifts.

An important strand of socio-technical research thus focuses on understanding the development of niches or socio-technical systems in the context of existing regimes. The perspective of these approaches is not so much on stability and discontinuous shifts but on the establishment and growth of socio-technical systems (notwithstanding the resistance this growth may face by the existing stable institutional and technical constellations). An example of such a type of approach is the concept of technology-specific or sectoral innovation systems meaning socio-technical configurations around specific technologies (such as photovoltaics), industry sectors (energy system) or societal demand areas (mobility). Several 'functions' have to be fulfilled for a successful evolution and performance of such systems (Jacobsson and Bergek, 2004, p.212):

- creation and diffusion of 'new' knowledge
- the guidance of the direction of search among users and suppliers of technology (…)
- the supply of resources such as capital and competencies
- the creation of positive external economies, both market- and non-market-mediated
- the formation of markets. Since innovations rarely find ready-made markets, these may need to be stimulated or even created. This process may be affected by governmental actions to clear legislative obstacles and by various organisations' measures to legitimise the technology.

The term 'function' can be misleading, and the proponents of this approach distance themselves from 'functionalist social theory' (see e.g. Hekkert et al., 2006) or replace the term by 'activities' within innovation systems or other terms. Analysing and mapping these activities or performance indicators along the diffusion of a technology (or set of technologies) may result in a differentiated picture of strengths and weaknesses in the development of, e.g., renewable energy technologies (Jacobsson and Johnson, 2000; Jacobsson and Lauber, 2006) and may help to identify the blocking mechanisms and policy strategies to remove these or to strengthen weak system functions (see e.g. Foxon et al., 2005). Functions of innovation systems direct our attention to both the prerequisites needed and the indicators for a successful transformation process towards long-term options in the transformation of energy systems.

However, the 'functions of innovation systems' approach is but one example of a broad range of concepts and research work within the 'social studies of technology' dealing with patterns in the conception and growth of socio-technical systems or actor-networks around new technologies or with the re-configuration of energy systems as socio-technical systems under changing socio-economic and regulatory conditions (see, for e.g. Summerton, 1996; Guy, Graham and Marvin, 1999; Jorgensen, 2005; Markard and Truffer, 2006). Such actor-oriented analyses also help to extend the traditionally supply-side-oriented perspective on energy systems and technologies towards the demand side – a perspective that highlights not only the active role of users in appropriating and integrating new technologies (Lie and Sørensen, 1996; Rohracher, 2003; Summerton, 2004) but also the restricted room for manoeuvre on the user side and the close interdependence of supply and demand side in 'systems of provision' (Chappells and Shove, 2004).

3 Visions, expectations and scenario-building

In addition to the analytic dimension of understanding and assessing socio-technical constellations and changes, social sciences may be useful in engaging with the prospective dimension of the transformation of energy systems. With respect to long-term system transformations, the issue of orienting change processes – and thus the topic of visions, expectations and continuous adaptation of such visions in social learning processes – is of special importance.

Visions and expectation may play an important role in the integration and alignment of different constituencies of actors towards a common aim; they signify the existing or possible technical alternatives and provide a framework towards which to orient the perceptions, decisions and behaviour of individual and collective actors during the processes and networks of technology development. Examples of such visions that align various actors have been elaborated, among others, for the case of the Diesel engine (as a thermodynamically perfect machine), the telephone and the idea of universal service or visions such as the data highway or the car-friendly city.

At the basis of this concept of visions lies the idea that innovations are generated not by the division of work between different disciplines but by the interference between different knowledge cultures (within engineering but also firms, politics, etc.). Visions serve as a bridge between these different cultures. The main functions of visions are threefold (Dierkes, Hoffmann and Marz, 1996, p.43):

- collective projection, as visions bring together people's intuitions and other types of knowledge about what appears feasible and desirable to them
- synchronic pre-adaptation, as visions integrate the various forms of perception and evaluation of the different actors producing technical knowledge and align them in the same direction
- functional equivalent, as visions stand in for shared, binding rule systems that do not yet exist in the communication between representatives of different knowledge cultures.

The effects generated by such integrative visions are, on one hand, cognitive activation, as these visions may be used to make new technical knowledge conceivable for different actors, on the other hand, personal mobilisation, as visions "activate the cognitive as well as the emotional, volitional, and affective potential of people, they mobilize the whole person" (ibid, p.52). Finally, visions may serve as an interpersonal stabiliser as they support the cooperation between and internalisation within the representatives of such interfering knowledge cultures.

While the concept of 'guiding visions' centres around stable metaphors serving as boundary objects between different knowledge cultures and actor groups, research on the role of expectations in technological change puts more emphasis on the dynamics and performativity of such long-term visions. Similar to 'guiding visions', expectations mediate across different boundaries – horizontally as a coordination of different actor groups or vertically across different levels of organisation (micro, meso and macro) (Borup et al., 2006). Visions and expectations operate at micro-, meso- and macro-level – ranging from rather short-term expectations of individuals or small groups of actors to collective long-term visions.

Expectations such as the nanorobot cleaning blood vessels constitute 'communicative spaces' that facilitate meaningful communication across different discourse logics (e.g. science, economics, mass media) and both limit and enable communication processes about the future of nanotechnology (see Lösch, 2006). Case studies on the dynamics of expectations, moreover, have been able to reconstruct the performativity of expectations, i.e. their role in creating agendas for relevant actors in innovation processes, attracting the interest of necessary allies, stimulating resources and support, and thereby to some extent 'perform' the futures they envision. However, expectations about the future of technologies and applications often exhibit their specific dynamics, e.g. Gartner consultancy's 'hype cycle' (Borup et al., 2006) claiming that in the early phase of technology development expectations often sore high and are followed by a 'trough of disillusionment' before they follow a more realistic 'slope of enlightenment'. Not least because of the performative and shared character of expectations, "visions, images and beliefs cannot sharply be demarcated from knowledge" (Nowotny, Scott and Gobbons, 2001, p.232).

As Eames and others argue, the example of the 'hydrogen economy' which has proved a powerful vision and active arena for the generation of technological expectations in the energy sector also shows us how heterogeneous such expectations often are:

> "At one extreme we find highly decentralised systems based on local production of hydrogen from domestic renewables, with hydrogen used to balance intermittent supplies and act as a major energy carrier. Others see hydrogen only as a transport fuel, based on centralised systems with large-scale production of hydrogen from nuclear power or fossil fuels, with an accompanying distribution infrastructure" (Eames et al., 2006, p.363).

The authors identify six overarching narrative themes around the hydrogen economy: 'community empowerment and democratisation', 'ecotopia', 'technical fix', 'independence and power', 'inevitability and technical progress' and 'staying in the race: hydrogen and the competitiveness agenda'. Visions about the technological future of a hydrogen economy thus possess a remarkable 'interpretative flexibility'. To become eventually realised, such visions "must move from performative expectation to niche experimentation, demonstration and use. In so doing it must become grounded in particular actor networks and specific places." (ibid, p.372) We will come back to this 'grounding' of expectations in the next section.

3.1 Interactive scenario-building and foresight

In dealing with long-term transformations of the energy system, social sciences may play a role not only in analysing visions and expectations but also in developing strategies to create spaces for learning and reflection in transition processes, such as the interactive creation of joint visions and images. The creation of several possible images of the future allows for an assessment, e.g. of the contribution to sustainable development, and subsequently the systematic development of pathways and measures required directing the transition process towards socially desired goals.

There is a considerable variety of scenario methodologies and ways of using scenarios (see e.g. van Notten et al., 2003; Börjeson et al., 2006). Scenarios are

> "typically defined as stories describing different but equally plausible futures that are developed using methods that systematically gather perceptions about certainties and uncertainties. Scenarios are not intended to be truthful, but rather provocative and helpful in strategy formulation and decision-making." (Selin, 2006, p.1).

As Weber points out, scenarios in general have moved away from a pure focus on science and technology and increasingly include market and social considerations; they become an increasingly participatory activity; and they have an emphasis on the contribution of foresight activities on shaping rather than predicting the future (Weber, 2006).

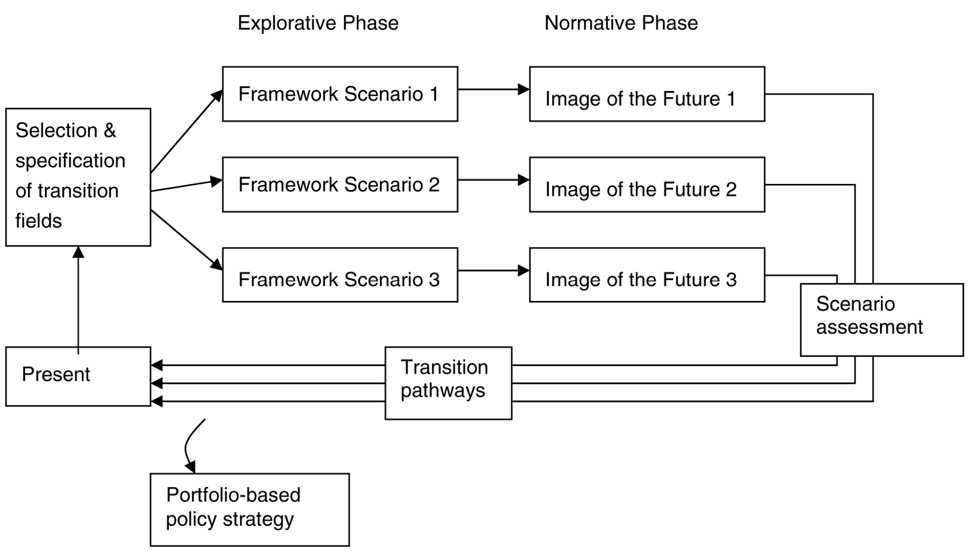
One of the fundamental distinctions is whether a scenario is explorative or normative. Explorative scenarios ask 'What can happen?' and explore different consistent visions of the future under varying external factors or perspectives. An example is the UK Futures scenario exercise where four basic types of development have been discerned along the dimensions 'social and political values (individual vs. community) and 'nature of governance' (interdependence vs. autonomy): world markets, global responsibility, local stewardship and national enterprise (Berkhout and Hertin, 2002). Sectoral visions, such as the development of energy systems, can then be modelled on the basis of these four fundamental types. Normative scenarios are also referred to as prospective, strategy, policy and intervention scenarios, and are rather about 'How can a certain target – e.g. sustainable energy system – be reached?' Normative scenarios are often followed by a 'backcasting' process, asking about the steps and strategies necessary to reach the envisioned future.

Scenarios may fulfil a number of functions for long-term change processes (see Wiek, Binder and Scholz, 2006): Most obviously they help to generate and integrate knowledge about complex future states and developments of the system and its contexts, discuss interrelationships, uncertainties or inconsistencies, but they may also contribute to building competence of the actors involved, facilitate and organise team work (e.g. enable negotiating different viewpoints) or counsel decision makers. However, Berkhout and others point out that not enough effort has been put in picturing social and economic futures as an essential component of the assessment of, e.g., climate change impacts. However, this deficit also has to do with some fundamental problems: "indeterminacy (imperfectly understood structures and processes), discontinuity (novelty and surprise in social systems), reflexivity (the ability of people and organizations to reflect about and adapt their behaviour) and framing (legitimately diverse opinions about the state of the world)." (Berkhout, Hertin and Jordan, 2002, p.93–94). Similar to the procedural functions of the scenarios mentioned earlier, Berkhout and Hertin also point to the importance of scenarios to engage actors in a process of social and organisational learning (often more important than the analytical results of scenarios), i.e. setting a frame for “iterative processes of self-reflection, change and adaptation within organisations” (ibid, p.94). Similar to the claims made for technology assessment in general, participative scenario development could play an “important role in reaching congruent meanings, which could then serve as the basis for joint action undertaken by different types of actors.” (Grin and Van de Graaf, 1996, p.96)

Foresight may thus be an important element of reflexive and adaptive governance strategies. Foresight in combination with adaptive planning may especially support strategic thinking about portfolios of options across different scenarios and during different phases of the policy cycle (Weber, 2006), and may thus enable second-order learning in policy-making. However, to be effective, the principles behind adaptive foresight have to be closely tied not only to policy design but also to policy implementation and learning, at a strategic as well as at a local level, Weber points out. The type of foresight and planning has to adapt to different phases and requirements as well: while initially system analysis and problem identification are on the agenda, the methods subsequently have to change to foresight with explorative and normative elements, backcasting processes to design pathways to sustainable system configurations, portfolio analysis to identify robust and adaptive policy options and finally strategy formulation that turns the so far open and participative into a closed process. After monitoring implementation success and changing framework conditions, the forecasting-planning cycle can be repeated to learn from past experiences and adjust to changes (Weber, 2006).

Figure 2 gives an example of such a process of ‘image creation’, assessment and ‘backcasting’ (as this creation of pathways starting with future images is called).

Figure 2 Constructing transition scenarios



Source: Weber et al. (2003).

4 Shaping socio-technical transformation processes

So far we have discussed some consequences of a social scientific conceptualisation of technology: the social embedding of technologies and technical change, i.e. a systemic perspective of integrated socio-technical systems, and the importance of visions, expectations and scenario-building for shaping and orienting the transformation of socio-technical systems. The interactive construction of scenarios as a tool for systematically thinking about the long-term perspective of the transformation processes mentioned earlier is already a bridge towards reflexive and adaptive strategies of policy-making for a long-term transition towards more sustainable energy systems, which will be sketched in this section. We will start with a short introduction to the concept of 'transition management' as a strategy to shape long-term transformation processes (a more detailed discussion of the concept and experiences with the Dutch 'energy transition' can be found in Loorbach et al., 2007, this issue) and move on to more micro-level-oriented and experimental strategies to shape the development and implementation of specific technologies.

4.1 Transition management

Building on an understanding of innovation processes as described earlier, the concept of transition management (Rotmans, Kemp and Van Asselt, 2001; Elzen, Geels and Green, 2004) aims at developing an exploratory, flexible way of policy-making with constant evaluation and adaptation of transition objectives and instruments, which decidedly focuses on long-term changes and changes at system level. The technological transitions addressed in these discussions are large-scale transformations of 'societal functions' such as transportation or energy provision. Such functions include not only the technical level but also the changes in other elements such as user practices, regulation, industrial networks or symbolic meaning (Elzen, Geels and Green, 2004). The main challenge certainly lies in the question how these general principles congeal into concrete policy as well as specific analyses and actions, but still these principles are valuable guideposts for a process-oriented view to policy-making in a context characterised by uncertainty and complexity as we have encountered in our discussion on the change of energy systems.

'Transition management' can be characterised by the following items:

- long-term thinking (at least 25 years) as a framework for shaping the short-term policy
- thinking in terms of more than one domain (multi-domain) and different actors (multi-actor) at different scale levels (multi-level)
- a focus on learning and a special learning philosophy (learning-by-doing and doing-by-learning)
- trying to bring about system innovation alongside system improvement
- keeping a large number of options open (wide playing field) (Rotmans, Kemp and Van Asselt, 2001, p.22).

At the heart of instruments to shape transition processes are strategies to organise processes of social learning, to set up socio-technical experiments and allow for an experimental way of policy-making, as well as strategies to collectively develop visions of transition goals, e.g. images of possible futures of the energy sector, and develop pathways to get there. Policy in such a context mainly assumes the role of coordinator and facilitator – also addressed in the concepts of policy networks and policy learning (see e.g. Schienstock, 2004).

Without going into detail, special emphasis must be placed on the adaptive and iterative character of transition policies and the iterative circles of developing visions and strategies, mobilising actors and implementing activities, monitoring progress and adapting the visions and strategies developed (cf. Loorbach et al., 2007, this issue).

With respect to the multi-level model of innovations described earlier in this paper, transition management strategies aim at radical shifts at the meso-level of socio-technical regimes. As regimes are usually deeply entrenched in broader social and technical structures, politics is hardly able to induce such shifts at will. Transition policy thus focuses on the modulation and coordination of various actors and activities involved in the ongoing system transformation processes. Regime changes, however, often originate at the micro-level of technological and market niches, where new technologies and innovations are bred. Fostering experiments and learning processes in such niches may thus be an important element to create more social and technological variety and increase the potential for regime changes.

4.2 Socio-technical experiments: strategic niche management

SNM and bounded socio-technical experiments (see, for example, Szejnwald Brown et al., 2003; Szejnwald Brown and Vergragt, forthcoming) both specifically refer to the creation of protected spaces (e.g. market niches, controlled field experiments) to broaden the design process by involving a broader range of actors and facilitate interactive learning of the participating actors. Socio-technical experiments are "driven by a long-term and large-scale vision of advancing the society's sustainability agenda, though the vision needs not be equally shared by its participants. Its goal is to try out innovative approaches for solving larger societal problems of unsustainable technologies and services." (Szejnwald Brown and Vergragt, forthcoming, p.6) A central aim of the development of niches similarly is to learn about the needs, problems and possibilities connected with the environmental innovation experimented with, and to help articulate design specifications, user requirements or side-effects of the innovation. Managing the development of environmental technologies in niches (and finding the right timing to open these niches to the wider market and competition) certainly is one of the more advanced and reflexive forms of managing environmental innovations and technologies by organising social learning process involving producers, technology designers and users in a joint process.

Experiences with SNM have, for example, been gained in the area of sustainable transport. An evaluation of a number of these examples discusses niche management processes at the level of transport technologies (e.g. various field experiments with electric cars and ultra-light electric vehicles) and at the level of experiments with the aim of reconfiguring mobility, such as car-sharing initiatives, bicycle-pool schemes or pilot projects on individualised public transport in France (cf. Hoogma et al., 2002).

Niche management is a form of broadening design processes by facilitating the interaction of a broader range of stakeholders and integrating the design process in a wider transition perspective (at least in the sense that current practices and social contexts are reflected). Referring to the related concept of constructive technology assessment, Johan Schot emphasises a number of characteristics of broadened design processes (cf. Schot, 2001): they should be anticipative, as users participating in the design process are expected to be more likely to bring up social issues and acceptance problems very early; they should be reflexive in the sense that actors are encouraged to recognise their own and others' perspectives and to consider technology design and social design as one integrated process; and they should finally lead to social learning processes, including 'second-order learning', i.e. not only articulating market demands but also questioning existing preferences and requirements in order to open up possibilities for more radical developments.

4.3 Social learning

This section finishes with a short note emphasising social learning as an integral part of the concepts and strategies presented earlier. Learning has been identified as a core element in successful innovation processes, and it has been pointed out that learning cannot be reduced to a cognitive act of knowledge appropriation, but that we can observe a number of different learning mechanisms and sources of learning, which are also referring to the embodiment of knowledge or the social character of knowledge creation. Various authors have thus expanded on learning-by-doing (cf. Arrow, 1962), learning-by-using (cf. Rosenberg, 1982) or learning-by-interacting between producers and users (cf. Lundvall, 1988), the latter being especially interesting for transition processes and the related actor reconfigurations.

With respect to the reflexivity of transition processes and the requirement of changes at system level, a further useful differentiation of learning processes can be applied: single-loop learning (sometimes also called first-order learning) vs. double-loop learning (second-order learning) (cf. Argyris, 1999). Chris Argyris developed this discrimination in the context of organisational learning: single-loop learning refers to a situation where a mismatch between intentions and outcome is corrected without questioning the underlying values of the system (comparable to the steering of a car), while double-loop learning may lead to a serious questioning of these values and attempts to identify 'governing variables', which are influencing actions and ultimately the outcome of these actions. Double-loop learning is thus more reflexive with respect to the context of action and underlying assumptions guiding one's activities. This type of learning is especially needed for profound system changes where simple adaptive strategies will not work any more.

5 A social science research agenda

Summing up, social-science-based strategies developed against the backdrop of socio-technical system transformation processes rather follow a communicative rationality than an instrumental rationality. Strategies presented in more detail earlier, such as socio-technical experiments within limited niches and the interactive creation of scenarios and future visions, usually have interactive and reflexive learning processes at their centre.

Energy policies striving to manage the long-term transition towards sustainable energy systems could make use of a range of strategies that are inspired by a socio-technical understanding of transition processes. To give a few examples, such strategies could include:

- a new culture of experiments and pilot projects
- support of interactive vision-building processes for the development of sustainable images of future energy systems and pathways to get there
- user involvement at different stages
- strengthening socio-technical systems (instead of isolated innovations) / focusing on system innovations
- providing spaces for learning and interaction
- keeping options open (avoiding early lock-in).

In the perspective presented in this paper, the focus is thus on the embedding of long-term options in ongoing transitions of the energy system and on the gradually adapting and differentiating long-term options through the outcomes of social learning processes gained in socio-technical niches, foresight exercises and actual implementation processes.

Social science research may provide an analytical basis to better understand the stability of the current energy system as an interrelation and mutual enforcement of social and technical elements (both within and in the context of the energy system) and on the same grounds understand the socio-technical dynamics of transformation processes. To this analytical dimension, social science research may also add a projective and reflexive dimension in facilitating the development of visions and scenarios for long-term changes and in inducing social and policy learning by reflecting on the grounds of change processes and constantly evaluating the outcome of interventions and socio-technical experiments.

References

Argyris, C. (1999) *On Organizational Learning*. Cambridge, MA: Blackwell Publishing.

Arrow, K.J. (1962) 'The economic implications of learning by doing', *Review of Economic Studies*, Vol. 29, pp.155–173.

Berkhout, F. and Hertin, J. (2002) 'Foresight futures scenarios: developing and applying a participative strategic planning tool', *Greener Management International*, Vol. 37, pp.37–52.

Berkhout, F., Hertin, J. and Jordan, A. (2002) 'Socio-economic futures in climate change impact assessment: using scenarios as "learning machines"', *Global Environmental Change*, Vol. 12, pp.83–95.

Borup, M., Brown, N., Konrad, K. and van Lente, H. (2006) 'The sociology of expectations in science and technology', *Technology Analysis and Strategic Management*, Vol. 18, pp.285–298.

Börjeson, L., Höjer, M., Dreborg, K-H., Ekvall, T. and Finnveden, G. (2006) 'Scenario types and techniques: towards a user's guide', *Futures*, Vol. 38, pp.723–739.

Chappells, H. and Shove, E. (2004) 'Infrastructures, crises and the orchestration of demand', in D. Southerton, H. Chappells and van B. Vliet (Eds), *Sustainable Consumption: The Implications of Changing Infrastructures of Provision* (pp.130–143). Cheltenham: Edward Elgar Publishing.

Dierkes, M., Hoffmann, U. and Marz, L. (1996) *Visions of Technology. Social and Institutional Factors Shaping the Development of New Technologies*. Frankfurt/New York: Campus Verlag.

Diesendorf, M. (1996) 'How can a "competitive" market for electricity be made compatible with the reduction of greenhouse gas emissions?', *Ecological Economics*, Vol. 17, pp.33–48.

Eames, M., McDowall, W., Hodson, M. and Marvin, S. (2006) 'Negotiating contested visions and place-specific expectations of the hydrogen economy', *Technology Analysis and Strategic Management*, Vol. 18, pp.361–374.

Elzen, B., Geels, F.W. and Green, K. (2004) *System Innovation and the Transition to Sustainability*. Cheltenham: Edward Elgar Publishing.

Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A. and Anderson, D. (2005) 'UK innovation systems for new and renewable energy technologies: drivers, barriers and system failures', *Energy Policy*, Vol. 33, pp.2123–2137.

Geels, F.W. (2004) 'From sectoral systems of innovation to socio-technical systems. insights about dynamics and change from sociology and institutional theory', *Research Policy*, Vol. 33, pp.897–920.

Geels, F. and Raven, R. (2006) 'Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003)', *Technology Analysis and Strategic Management*, Vol. 18, pp.375–392.

Grin, J. and Van de Graaf, H. (1996) 'Technology assessment as learning', *Science, Technology, and Human Values*, Vol. 21, pp.72–99.

Guy, S. and Marvin, S. (1998) 'Electricity in the marketplace: reconfiguring the consumption of essential resources', *Local Environment*, Vol. 3, pp.313–331.

Guy, S., Graham, S. and Marvin, S. (1999) 'Splintering networks: the social, spatial and environmental implications of the privatization and liberalization of utilities in Britain', in O. Coutard (Ed.), *The Governance of Large Technical Systems* (pp.149–169). London: Routledge.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S. and Smits, R.E.H.M. (2006) 'Functions of innovation systems: a new approach for analysing technological change', *Technological Forecasting and Social Change*, Vol. 74, pp.413–432.

Hoogma, R., Kemp, R., Schot, J. and Truffer, B. (2002) *Experimenting for Sustainable Transport: The Approach of Strategic Niche Management*. London: Spon Press.

IPCC (2007) '*Climate change 2007: Mitigation. Contribution of Working group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Jacobsson, S. and Bergek, A. (2004) 'Transforming the energy sector: the evolution of technological systems in renewable energy', in K. Jacob, M. Binder and A. Wieczorek (Eds), Paper presented in the Proceedings of the *2003 Berlin Conference on the Human Dimensions of Global Environmental Change: Governance for Industrial Transformation* (pp.208–236). Berlin: University of Berlin.

Jacobsson, S. and Johnson, A. (2000) 'The diffusion of renewable energy technology: an analytical framework and key issues for research', *Energy Policy*, Vol. 28, pp.625–640.

Jacobsson, S. and Lauber, V. (2006) 'The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology', *Energy Policy*, Vol. 34, pp.256–276.

Jorgensen, U. (2005) 'Energy sector in transition – technologies and regulatory policies in flux', *Technological Forecasting and Social Change*, Vol. 72, pp.719–731.

Kemp, R., Rip, A. and Schot, J. (2001) 'Constructing transition paths through the management of niches', in R. Garud and P. Karnře (Eds), *Path Dependence and Creation,* Mahwah (pp.269–299). New Jersey/London: Lawrence Erlbaum Associates.

Lie, M. and Sørensen, K.H. (1996) *Making Technology our Own? Domesticating Technology into Everyday Life*. Oslo: Scandinavian University Press.

Lösch, A. (2006) 'Anticipating the futures of nanotechnology: visionary images as means of communication', *Technology Analysis and Strategic Management*, Vol. 18, pp.393–409.

Lundvall, B-Å. (1988) 'Innovation as an interactive process: from user-producer interaction to the national system of innovation', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (Eds), *Technical Change and Economic Theory* (pp.349–369). London/New York: Pinter.

Markard, J. and Truffer, B. (2006) 'Innovation processes in large technical systems: market liberalization as a driver for radical change?', *Research Policy*, Vol. 35, pp.609–625.

Marwell, N.P. and McInerney, P-B. (2005) 'The Nonprofit/For-Profit continuum: theorizing the dynamics of mixed-form markets', *Nonprofit and Voluntary Sector Quarterly*, Vol. 34, pp.7–28.

Mayntz, R. (1993) 'Große technische systeme und ihre gesellschaftstheoretische bedeutung', *Kölner Zeitschrift für Soziologie und Sozialpsychologie*, Vol. 45, pp.97–108.

Nowotny, H., Scott, P. and Gibbons, M. (2001) *Re-Thinking Science. Knowledge and the Public in an Age of Uncertainty*. Cambridge: Polity Press.

Pehnt, M., Cames, M., Fischer, C., Praetorius, B., Schneider, L., Schumacher, K. and Voß, J-P. (2006) *Micro Cogeneration. Towards Decentralized Energy Systems*. Berlin: Springer.

Raven, R.P.J.M. (2006) 'Towards alternative trajectories? Reconfigurations in the Dutch electricity regime', *Research Policy*, Vol. 35, pp.581–595.

Ringel, M. (2003) 'Liberalising European electricity markets: opportunities and risks for a sustainable power sector', *Renewable and Sustainable Energy Reviews*, Vol. 7, pp.485–499.

Rip, A. and Kemp, R. (1998) 'Technological change', in S. Rayner and E.L. Malone (Eds), *Human Choice and Climate Change: Resources and Technology*, Vol. 2, (pp.327–399). Columbus: Ohio: Batelle Press.

Rohracher, H. (2003) 'The role of users in the social shaping of environmental technologies', *Innovation*, Vol. 16, pp.177–192.

Rosenberg, N. (1982) *Inside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press.

Rotmans, J., Kemp, R. and Van Asselt, M. (2001) 'More evolution than revolution: transition management in public policy', *Foresight*, Vol. 3, pp.15–31.

Schenk, N.J., Moll, H.C. and Schoot Uiterkamp, A.J.M. (2007) 'Meso-level analysis, the missing link in energy strategies', *Energy Policy*, Vol. 35, pp.1505–1516.

Schienstock, G. (2004) 'From path dependency to path creation: a new challenge to the systems of innovation approach', in G. Schienstock (Ed.), *Embracing the Knowledge Economy. The Dynamic Transformation of the Finnish Innovation System* (pp.3–27). Cheltenham: Edward Elgar.

Schot, J. (2001) 'Towards new forms of participatory technology development', *Technology Analysis & Strategic Management*, Vol. 13, pp.39–52.

Selin, C. (2006) 'Trust and the illusive force of scenarios', *Futures*, Vol. 38, pp.1–14.

Summerton, J. (1996) 'Of watts, wires and webs: reshaping electricity', in L. Ingelstam (Ed.), *Complex Technical Systems* (pp.87–107). Stockholm: Swedish Council for Planning and Coordination of Research (FRN).

Summerton, J. (2004) 'Do electrons have politics? Constructing user identities in Swedish electricity', *Science, Technology, and Human Values*, Vol. 29, pp.486–511.

Szejnwald Brown, H. and Vergragt, P.J. (forthcoming) 'Bounded socio-technical experiments as agents of systemic change: the case of a zero-energy residential building', *Technological Forecasting and Social Change*.

Szejnwald Brown, H., Vergragt, P., Green, K. and Berchicci, L. (2003) 'Learning for sustainability transition through bounded socio-technical experiments in personal mobility', *Technology Analysis and Strategic Management*, Vol. 15, pp.291–315.

Thomas, S. (2006) 'The grin of the Cheshire cat', *Energy Policy*, Vol. 34, pp.1974–1983.

van Notten, P.W.F., Rotmans, J., van Asselt, M.B.A. and Rothman, D.S. (2003) 'An updated scenario typology', *Futures*, Vol. 35, pp.423–443.

Verbong, G. and Geels, F. (2007) 'The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004)', *Energy Policy*, Vol. 35, pp.1025–1037.

Watson, J. (2004) 'Selection environments, flexibility and the success of the gas turbine', *Research Policy*, *Vol.* 33, pp.1065–1080.

Weber, K.M. (2006) 'Foresight and adaptive planning as complementary elements in anticipatory policy-making: a conceptual and methodological approach', in J-P. Voß, D. Bauknecht and R. Kemp (Eds), *Reflexive Governance for Sustainable Development* (pp.189–221). Cheltenham: Edward Elgar.

Weber, K.M., Leitner, K-H., Oehme, I., Rohracher, H., Späth, P. and Whitelegg, K. (2003) 'Middle-range transitions in production-consumption systems: the role of research programmes for shaping transition processes towards sustainability', Paper presented in the Proceedings of the *Conference on the Human Dimensions of Global Environmental Change: Governance for Industrial Transformation*, Berlin: IHDP.

Wiek, A., Binder, C. and Scholz, R.W. (2006) 'Functions of scenarios in transition processes', *Futures*, Vol. 38, pp.740–766.

Winskel, M. (2002) 'When systems are overthrown: the "dash for gas" in the British electricity supply industry', *Social Studies of Science*, Vol. 32, pp.563–598.

Notes

[1]CCGT is seen to be closely linked to liberalised energy markets and one of the main factors for the UK 'Dash for Gas'. Compared to coal or nuclear based energy generation technologies, gas turbines are characterised by a high efficiency of fuel use for electricity generation (up to 60%), short lead times for planning and construction, low construction costs (though in turn high dependence on gas prices) and consequently high return on investments. These characteristics have a close fit with the short-term orientation of liberalised markets, although they have turned out to be successful under other selection environments, too (Watson, 2004). However, as Winskel (2002) describes, there is much more behind the 'Dash for Gas' than a fit of technology with institutional and economic requirements of liberalised markets.

[2]For a discussion of micro-generation technologies, see also the contributions of Sauter and Fischer in this issue.

[3]Thomas (2006, p.1979) points out that in the UK, software development houses have probably been the biggest winners from electricity market liberalisation – the development of software for the British wholesale electricity market NETA alone, often called the most complex suite of computer programmes ever built in the UK, took 5 years for the development and implementation at a cost of around 1.5 billion pounds. The software to allow retail competition for end-customers costs another 800 million pounds.

Deploying wind power in Australia: a socio-technical analysis

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Abstract: Conventional explanations for Australia's historically scant use of wind energy in power generation have focused on wind power's cost and undesirable technical characteristics (particularly intermittency). This paper argues for a more comprehensive explanatory framework, drawing on insights from the Social Shaping of Technology. This framework combines contextual historical and interpretive approaches to analyse this history of wind power. The contextual historical approach deals with the structure of and changes to the Australian electricity sector and the evolution of renewable energy policy, which have shaped the use of wind power. This approach is supplemented with an analysis of how wind power has been interpreted by various protagonists over time and how the interpretations have shaped the way in which wind power has been promoted or rejected. Wind power has been widely regarded as an 'environmental technology', a notion that has embodied a variety of socio-political visions. Wind power also exhibits different technical characteristics to conventional generators, and yet is required to fit into an existing system. Hence wind power's technical capability has been a source of much debate.

Keywords: electricity sector – Australia; energy policy – Australia; renewable energy policy; science and technology studies; sustainable energy policy; wind power.

Reference to this paper should be made as follows: Bunting, A. (2008) 'Deploying wind power in Australia: a socio-technical analysis', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.162–175.

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1 Introduction

Globally, wind power technology is experiencing rapid growth. In Australia, its fortunes have been mixed. It has made inroads into remote area power supplies, where it can partly supplant diesel fuel; however, this market is small. The use of grid-connected wind power grew rapidly in Australia after a renewable energy support mechanism was introduced in 2001, with currently around 800 MW of capacity installed. However, this support mechanism will soon end and the prospects for wind power are looking uncertain. While the southern parts of Australia have an excellent wind resource, Australia also has vast quantities of coal, natural gas and hydro resources, and has long relied on cheap energy to attract energy-intensive industries.

Traditional explanations for the scant deployment of wind power in Australia usually fall into two camps. The electricity industry and policy makers have typically argued that wind power is too expensive compared with conventional sources, and that it has undesirable technical characteristics, particularly intermittency, which severely limit its value. Advocates of wind power (mostly environmentalists), on the other hand, have argued that wind power has faced enormous institutional barriers (Blakers et al., 1991). They have singled out the electricity industry for its commitment to large centralised power stations and for favouring conventional energy sources.

While not disparaging the significance of cost, intermittency and the structure of the electricity sector as barriers to wind power, it is argued that these explanations are not sufficient. This paper examines Australia's history in utilising wind power, and drawing on insights from the Social Shaping of Technology (SST), puts forward a framework for analysing this history. SST perspectives focus on how social structures and social processes shape the development and use (or non-use) of a technology. This framework draws on both structure-oriented and actor-oriented perspectives: it incorporates an analysis of the structure of the energy sector and an analysis of how actors interpret the technology and how these interpretations guide their actions.

In the next section, relevant literature in SST is briefly reviewed, and following this, the framework used in this paper is described. This is applied to the case study in the sections following. The broader study on which this paper is based draws mainly from documentary evidence from the electricity industry and governments, and papers by energy commentators, supplemented by some interviews and informal communication with key players from the electricity sector, wind industry and environment movement.

It is not intended in this paper to address the policy question of how greater usage of wind power in Australia could be advanced. Rather, the purpose is analysis. This framework is intended to enable a better understanding of the complexities of the factors influencing the use of wind power. However, in the conclusion, suggestions are made as to what lessons wind power advocates might draw.

2 The social shaping of technology

A key influence on this study is Russell's analysis of why the UK failed to make significant use of combined heat and power schemes (Russell, 1993). Russell's starting point is the institutional arrangements in the electricity industry and local and central government. He highlights how knowledge claims about energy technologies come to be aligned with institutional interests in the sector.

Other analysts have specifically addressed wind power. Hirsh and Serchuk (1996) and Heymann (1999) analyse whether wind power is compatible with the existing arrangements in the electricity sector. While Hirsh and Serchuk regard large-scale wind systems as compatible because they do not affect how electricity is used, Heymann argues that the demise of small-scale wind systems in the early 20th century was due to their incompatibility with the emerging centralised electricity systems. He argues that the 1990s renaissance of wind power occurred when the paradigm of centralised power stations was starting to break down.

Baumgartner and Burns (1984) put forward a framework for analysing the compatibility of alternative energy technologies with an existing system, taking as their starting point the existing technological and organisational arrangements and external support structures. They also add an important dimension: existing cultural infrastructure, that is, how "cognitive frames and values in a given culture" affect how the new technology is perceived. Hård and Jamison (1997) analyse how the established technologies are reinforced by symbolic, organisational and behavioural structures. They claim: "Alternative technologies often succeed or fail largely on the basis of the symbols or visions which are associated with them." (p.147).

Recently, analysts have looked at the role of 'niches', spaces where a new technology is temporarily shielded from market forces and allowed to mature, and 'experiments' within the niche, which allow for learning (see for example Kemp, Rip and Schot, 2001). Verheul and Vergragt (1995) note that niches and associated experiments are promoted by groups (typically environmentalists) who disagree with the conventional interpretations and evaluations of these technologies. How debates over differing interpretations of a new technology affect its development path has been demonstrated by Bijker (1995). He shows how different social groups, employing different assumptions of the purpose of a new technology and appropriate uses and usage patterns, disagree on how well a new technology 'works'. The path of a new technology thus requires a social explanation.

Drawing on these insights, a framework for analysing the history of wind power in Australia is put forward, comprising three themes.

1 The contextual historical theme deals with the structure of and changes to the Australian electricity sector and the evolution of renewable energy policy, and shows how these have shaped the history of wind power.

2 The second theme deals with the interpretation of wind power as an 'environmental technology'. Environmentalists have long advocated wind power as a remedy for environmental concerns; thus the socio-political visions associated with wind power have reflected ideas about the role of technology in environmental amelioration.

3 The third theme deals the technical capability of wind power in the electricity grid. This has proved to be a controversial issue for wind power, because it exhibits quite different technical characteristics to conventional forms of electricity generation. However, electricity systems are not designed around the characteristics of wind power; rather, wind is required to fit into an existing electricity system. How well wind power 'works' in a system and thus its value depends on a range of assumptions, practices and standards, as well as the characteristics of other elements in the electricity system.

3 The historical context

3.1 The Australian electricity sector

Australia is a federation of six states and two territories, with electricity supply being the responsibility of the states. To ensure security of supply, state governments favoured the energy resources located within state borders. Some states have vast quantities of coal or sites suitable for hydro; others are less well endowed. Minerals and energy resources are now Australia's largest export industry; and successive governments have sought to support the minerals sector through provision of plentiful, cheap energy.

Traditionally, electricity demand grew rapidly, and the utilities built increasingly larger power stations with little regard for environmental concerns and encouraged growth in electricity demand, as indeed was required under their charters. (For example, Victoria, *State Electricity Commission Act 1958*.) Circumstances changed in the late 1970s: environment groups waged campaigns against new power stations, demand growth slowed, and electricity utilities were criticised for their lack of accountability. Governments sought greater control over electricity utilities, with Victoria leading the way following the 1982 election of a Labor government. The Labor Party had been influenced by environment battles over new power stations and sought to reform the State Electricity Commission of Victoria (SECV), including requiring the SECV to consider energy conservation and renewable energy (Victoria, *State Electricity Commission (Amendment) Act 1982*). This led to the first major study of the wind energy resource, discussed in the next section.

The state where conditions for wind power are the most promising is South Australia (SA): the wind resource is excellent and fossil fuel resources are problematic. SA's coal supplies are remote and of poor quality, and uncertainties over natural gas contracts have plagued the state government. SA first investigated the potential for large-scale wind power in the 1950s (Mullett, 1957). In that period, the prospect of energy shortages led several European countries to develop wind turbines. But, the promise of nuclear power and the further discoveries of oil in the early 1960s ended wind turbine development, and therefore any likelihood of wind power in SA.

In the early 1980s, anticipating a large price rise for natural gas, the SA government investigated the potential of alternative fuel supplies, including wind power. It recommended that the state's wind resource be investigated, and a demonstration wind farm be constructed (SA, 1984). But fears of future electricity shortages were short-lived. In 1990, SA's electricity grid was interconnected with neighbouring Victoria, which had excess generating capacity. This ended, for a time, SA's interest in wind power.

Australia's plentiful cheap electricity from coal-fired power stations was traditionally regarded as offering a major economic advantage. This became problematic after the enhanced greenhouse effect became a public policy issue in 1988. Some of the utilities responded to the challenge. In Victoria, the SECV examined emission-reduction scenarios, including a massive increase in the use of wind power (SECV, 1989). Under pressure from a state government keen to court the green vote, the SECV began planning for Australia's first grid-connected wind farm. This plan, however, was short-lived. In 1992 a new Victorian government was elected, and it proceeded rapidly to disaggregate and privatise the SECV. The wind farm and most other sustainable energy initiatives were shelved. In New South Wales (NSW), the electricity utility also took a more proactive role in the light of concerns about GHG emissions. It hoped that renewable energy could offer significant business opportunities and initiated several renewable energy initiatives including an assessment of the state's wind resources (Schuck, 1991), and in 1997 the construction of Australia's first grid-connected wind farm.

By the late 1990s, the electricity utilities had been broken up, corporatised or privatised, and a National Electricity Market established. These changes have been driven by the Federal Government, in part to further reduce the cost of energy to industry. The new electricity companies were more removed from government influence and hence were unlikely to install wind power capacity without an economic incentive. Future grid-connected wind power installations would require specific support mechanisms. These are discussed in the next section. But overall, these support mechanisms have been relatively small scale. Energy-intensive industries have a large influence on government energy policy, and have strongly opposed measures that they consider may increase electricity prices, such as support for renewable energy.

3.2 Renewable energy policy in Australia

Before the enhanced greenhouse effect emerged on the public policy agenda, Australian policy makers typically regarded renewable energy as useful only where it could substitute for liquid fuels. Thus most renewable energy policy was targeted at remote area power supplies to displace diesel. Photovoltaics were the preferred Renewable Energy Technology (RET) – partly because Australia has significant research expertise in this area.

Renewable energy policy was mainly a state government responsibility. Until recently, the federal government played little role other than providing funding for renewable energy research, development and demonstration. Funding was targeted at technologies where Australia already had research capability, with wind power receiving only a small proportion of funding.

The state governments differed significantly in their renewable energy policies. Western Australia (WA) has many remote communities supplied by diesel generators. Since electricity utilities were obliged to offer uniform tariffs, they had a strong incentive to consider alternatives. Many remote areas have a better solar resource than wind. However, WA has several coastal remote communities with good winds, and during the 1980s became the leading state to experiment with remote area wind power.

In Victoria, the prospects for RETs were promising for quite different reasons. The Liberal (conservative) Premier of Victoria during the 1970s, Rupert Hamer, was a supporter of solar energy, and in 1977 established a committee to advise on funding for solar energy (then the umbrella term for 'renewable energy'). In 1981, this became the Victorian Solar Energy Council (VSEC).

The 1982 election of a Victorian Labor government led to more significant developments. The government was keen to promote energy conservation and renewable energy, and directed VSEC to develop a state renewable energy strategy and to focus on stimulating a local manufacturing industry of RETs, particularly in solar heating appliances. It also directed the SECV to work with VSEC on assessing Victoria's wind energy resources, a study which found that sections of coastal Victoria had an excellent wind regime (SECV and VSEC, 1987).

This early enthusiasm for renewable energy, however, was short-lived. The Victorian government's interest in renewable energy was only a minor part of its overall energy policy. Its main focus was on fostering economic growth through exploiting Victoria's significant fossil fuel resources, particularly brown coal (lignite). Victoria's brown coal resource is of poor quality, but it is abundant and cheap to mine and therefore is used for onsite power generation. The government was keen to attract energy-intensive industries – hardly compatible with its promotion of renewable energy and energy conservation. And by the mid 1980s, interest in renewable energy was waning in Australia and overseas.

In 1988, interest in renewable energy re-emerged. Major publicity about the threat of climate change from Greenhouse Gas (GHG) emissions saw renewable energy redefined as a GHG-free energy source. With the growing 'green' consciousness of the electorate, state and federal governments responded with some measures, albeit small, to encourage the use of RETs, but mostly focused on its use in remote areas where it could supplant liquid fossil fuels.

Although RETs had low GHG emissions, they were still supply-side options. Increasingly policy makers stressed that the best short-term strategy to reduce GHG emissions was to reduce demand through energy efficiency. Australia had significant scope to increase the efficiency of energy usage: energy prices were low, providing little incentive for efficient use. Yet, improving energy efficiency has proved difficult, compared with the easier option of increasing supply. Renewable energy has popular appeal; thus governments find it easier to stimulate the renewable energy industry. By this time, governments were keen to develop new export markets for Australian-manufactured goods. Because of local expertise, the renewable energy technologies that offered the best opportunity for developing export markets were RAPS and solar water heating. There was less scope to develop an export-oriented wind energy industry, since other countries, particularly Denmark, already dominated the market.

From the late 1980s onwards, the federal government was also determined to restructure the electricity sector. Australia's electricity sector relied very heavily on coal, and the government was aiming to reduce electricity prices, which was likely to increase demand. Suggestions that GHG emissions should be reduced were a significant threat to this plan. Policy responses to the greenhouse agenda was weak, with the federal government mostly portraying GHG reductions as detrimental to industry, rather than offering new business opportunities (for example, Industry Commission, 1991.) This view persisted after a change of government in 1996, despite increased international pressure on Australia from the Kyoto Protocol process.

The Kyoto climate change conference of 1997 did, however, lead to the introduction of a support mechanism that provided a significant boost for renewable energy, particularly wind power. As part of its bargaining position at Kyoto, the federal government promised measures targeted at renewable energy, including a 2% increase in the amount of electricity generated from renewable energy. The measure was introduced in 2001 as the Mandatory Renewable Energy Target (MRET), but the 2% increase was changed to a fixed annual energy increase of 9,500 GWh per year, based on the electricity forecast that later proved far too low. Thus the percentage increase in renewable energy will be much less than 2%. The target increase in renewable generation ramps up until 2010, and then remains steady until 2020 when the measure expires.

MRET provided a significant boost for renewable energy, particularly wind power, in about the first 5 years of the measure. However, because the ramping-up of the target ends in 2010 and investors have only until 2020 to earn extra income from the measure and because a large amount of renewable energy generation is already being planned or constructed, there is little incentive for further investment. The renewable energy industry lobbied intensively for MRET to be increased and extended, but such calls were rejected by the federal government (Commonwealth of Australia, 2004). The government has shifted its support to provide funding for the demonstration of large-scale technologies that promise very large reductions in GHG emissions. It is widely expected that this would benefit 'cleaner coal' technologies, such as carbon capture and storage through geosequestration.

State governments also, to varying degrees, provided support for renewable energy. However, with the development of a National Electricity Market and the corporatisation or privatisation of the electricity authorities, state governments had much less control over the electricity industry.

To date, the most effective renewable energy support mechanism introduced by a state government has been green power. This is a voluntary scheme, whereby electricity customers can choose to pay a premium on their power bills for an additional amount of energy to be generated from renewable energy. NSW has driven this process. In 1997, it developed accreditation guidelines to ensure that at least 60% (later 80%) of the 'green power' sold came from the generators using renewable energy, and persuaded all the state's electricity retailers to offer green power. Later, the schemes spread to other states. Green power has stimulated the development of some wind power, albeit less than MRET.

Since the federal government announced that it would not extend MRET, the state governments have been considering how they can put in place a replacement. This is difficult because the electricity market is now national. However, there is currently a good prospect for inter-state cooperation, since all of the states have Labor governments, while the federal government is a conservative coalition. Victoria is particularly supportive of wind power, and has set ambitious targets for the development of wind power and other renewable energy facilities. It has recently introduced a state-based renewable energy support mechanism, but at the time of writing the future and impact of this mechanism is unclear.

4 The idea of an environmental technology

Here the second theme is discussed, which relates to how wind power is interpreted. Since the 1970s, advocates of wind power have portrayed it as a benign alternative to environmentally damaging energy technologies. This section is an analysis of this representation of wind power as an environmental technology and the socio-political visions associated with such technologies.

Here the label 'environmental technology' is used to describe technologies that are promoted as a means of ameliorating environmental problems. The label is also used normatively: it evokes an image of desirability. It is useful to regard this label 'environmental technology' and indeed also 'environmental problem' as socially constructed – at least to an extent. This is qualified, because it does not imply an endorsement of the more radical interpretations of social constructivism. (For an overview, see Sismondo, 1993.) For example, some who study the social construction of environmental problems have been criticised for being agnostic about the existence of environmental problems and the capacity of certain technologies to alleviate such problems (Burningham and Cooper, 1999). On the other hand, it is clear that some groups may frame and prioritise environmental problems in a way that favours a 'solution' they have an interest in.

The intention here is not to deconstruct 'environmental problems' – these are taken to be the concerns raised by various environment actors. Instead, the intention is to examine this common categorisation of wind power as an environmental technology, while recognising that this categorisation is contested. For example, groups who oppose wind power facilities due to visual impact or danger to birds have challenged the popular view of wind power as an environmental technology. Instead, they portray wind power facilities as industrial plants in order to evoke an anti-environmental image. The wind power industry has an advantage in that it can latch onto and reinforce a long-standing, popular interpretation of wind power as environmentally benign. Much of its current communication strategy is aimed at maintaining the robustness of this interpretation.

The environmental concerns linked with wind power, how wind power has been portrayed as a remedy and the social visions associated with environmental technologies have differed significantly over time and among different groups. This relates to the transformation of the environment movement since the 1960s. Jamison (2001) identifies six phases in this transformation, from the dawn of an ecological awareness through to the modern age of green business. In this section two main periods are discussed: the decade following the 1973–1974 oil shock, when fears of future energy shortages emerged; and the period since the late 1980s, when the greenhouse effect came onto the political agenda, and the discourse of 'ecological modernisation' started to gain ground (Hajer, 1995). In the first period, the environmental concerns for which wind power was portrayed as a remedy included resource depletion, wilderness loss from hydropower, nuclear power; in the second period, wind power was predominantly portrayed as a GHG-free energy source.

Some 1960s environmentalists were quite negative about modern technology, which they regarded as responsible for environmental problems (Cotgrove, 1975). In the early 1970s, a more optimistic viewpoint emerged, advocating the development of 'alternative' technologies. The Alternative Technology (AT) movement was quite diverse, but efforts to develop environmentally benign technologies were fundamental. Some in the AT movement focused mainly on the technologies; others saw alternative technologies as integral to a better way of life such as a means to greater self-reliance, or as amenable to community control and public participation. Key people who popularised this holistic view were Schumacher (1973), who emphasised the 'appropriateness' of these technologies for the Third World, and Lovins (1977) who linked 'soft energy' with an improved social order.

Some environmentalists also raised concerns about resource scarcity. The 1970s oil shocks added weight to these fears, focusing these on energy resource depletion. Thus, energy became an important issue for the environment movement, and renewable energy began to be seen as an environmental solution. Some governments were planning a large increase in nuclear power capacity, leading to a burgeoning anti-nuclear movement. Some anti-nuclear activists, keen to demonstrate the viability of renewable energy as an alternative to nuclear power, joined the ranks of the AT movement. This led to a change in the social visions associated with renewable energy, diminishing the original ideas of small-scale installations to enhance self-reliance.

Australia also developed a strong anti-nuclear movement, focused on opposition to uranium mining, since nuclear power was unlikely in Australia. But Australian environmentalists had more local concerns about new electricity generation projects.

Indeed probably the most significant environmental campaign in Australia's history, galvanising environmentalists across the nation, was the opposition to wilderness destruction from the building of large-scale dams for hydro-electric plant in Tasmania. This campaign, and others, made the environment movement highly critical of the electricity utilities' quest for expansion and disregard for environmental concerns. These campaigns spawned a new generation of energy experts who hoped to challenge the traditional expertise of the electricity utilities. Many of these new energy experts promoted energy conservation and renewable energy. They also differed from the earlier AT enthusiasts in that they focused on how renewable energy could be incorporated into the mainstream electricity system.

Among these new energy experts were the founders of Australia's first wind power advocacy group: the Australasian Wind Energy Association (AusWEA). In the early 1980s, AusWEA became heavily involved in the Tasmanian anti-hydro campaign, promoting wind power as an alternative [Senate Select Committee (SSC) on South West (SW) Tasmania, 1982]. They put forward an image of wind power as compatible with large-scale hydro-based electricity systems, while avoiding the environmental damage caused by hydropower. Wind power, they claimed, was more environmentally benign, not only because it could be deployed in agricultural rather than wilderness areas but also because it could be built quickly and modularly, if and when electricity demand grew. Hydropower stations, however, required long lead times. Should long-term electricity forecasts prove too high – as occurred during the 1980s – electricity utilities would be left with overcapacity, and would therefore actively promote much greater use of electricity. Wind power was thus portrayed not just as a supply-side technology but also as compatible with efforts to reduce electricity demand.

While the Tasmanian campaign against hydropower was in part successful – a newly elected federal Labor government stopped the most controversial project in 1983 – the push for wind power as an alternative was not. In its campaign, AusWEA had a somewhat receptive ear from the federal Labor Party for consideration of wind power for Tasmania; but this was soon rejected when Labor came into government (Blakers, 1984).

By this time, interest in renewable energy was starting to wane, both in policy circles and in the environment movement. Soon AusWEA's membership was in decline, and in 1987 it dissolved into the Australian and New Zealand Solar Energy Society. The advocacy voice for wind power was thus greatly diluted.

In the late 1980s, environmentalism re-emerged, in part due to a media campaign focused on global environmental problems, including the enhanced greenhouse effect. No longer would renewable energy be depicted as just a solution to resource scarcity, or an alternative to nuclear power: arguments that in fact carried little weight in Australia. It was now depicted as an energy source that emitted no GHGs during operation. For the supporters of renewable energy, this provided a much stronger argument for renewable energy, particularly in Australia where emissions from electricity generation are very high.

During this period, views of the role of environmental technologies were starting to shift. The idea that environmental protection and economic growth are antithetical started being replaced with the message of 'ecological modernisation', that reducing environmental impact can be compatible with economic growth and may enhance business competitiveness (Weale, 1992). Some companies came to regard environmental technologies as offering new business opportunities. The linking of environmental problems with business opportunities adds a new dimension to the prioritising of environmental problems, and what constitutes an appropriate solution to an environmental problem. 'Green' businesses are keen to identify as critical those environmental problems that their product can address, and to portray their product as the solution to the identified problem.

In Australia, the business sector and policy makers have been slow to embrace the message of ecological modernisation. Indeed, there has been much opposition to the idea that Australia should reduce its GHG emissions. Energy-intensive industries have continually argued that measures to reduce emissions will impose heavy costs and reduce Australia's competitive advantage. On the other hand, some companies, including those with a large interest in fossil fuels, are starting to embrace renewable energy.

Since Australia introduced MRET, the wind power industry has grown significantly. Previously, there were only a handful of very small companies focusing on small-scale systems. The opportunities provided by MRET led new businesses to emerge, existing larger companies to move into the wind power industry and overseas wind power companies to set up branches in Australia. The wind power industry has portrayed wind power as a means not only of reducing GHG emissions but also of creating jobs in rural and regional areas. Thus, the introduction of MRET has meant that the support base for wind power has widened significantly.

The rapid growth of wind power under MRET has also led to a shift in popular perceptions of wind power. For many, wind power and other forms of renewable energy are strongly identified with environmental improvement. But Australia has a history of controversy over the environmental impact of some renewable energy sources, principally hydro-electric plant that lead to flooding of wilderness areas, and some forms of biomass. Wind power is now also becoming one of these controversial forms of renewable energy – as indeed it is in other countries.

Many wind farm developers originally saw coastal Victoria as ideal for wind power – the wind regime is excellent, there is good access to grid infrastructure, and the state government is supportive. However, many windy areas in coastal Victoria are also very scenic, and sections of local communities have been very hostile towards wind power, pointing to its detrimental environmental impacts. Most opponents cite the visual impact of wind farms on scenic areas as the prime reason for their objection, though noise and the threat to endangered species of birds are also cited. (For an overview of opponents' concerns see Mercer, 2003.) The controversy has now become highly politicised at both state and federal government level.

Some opponents of wind farms have pointed out that although wind power does not produce GHG emissions, it is still a supply-side technology, and that the priority should be to reduce demand, rather than to build more electricity generating capacity. Australia's electricity demand is forecast to grow significantly, with wind power having very little effect on the growth in GHG emissions. Australia also has significant scope for improving energy efficiency, although estimates of the potential for savings vary widely (Australian Government, Productivity Commission, 2005). But energy efficiency is not well understood by the general public or perhaps even by politicians. Moreover, it involves a myriad of small changes that are far less visible and politically appealing, compared with the opening of a brand new wind farm. Wind power is thus seen as offering just another development opportunity, albeit one with a green gloss.

5 The technical capability of wind power

The third theme deals with the question of how well wind power 'works'. Historically, electricity authorities had been required by the Acts under which they were instituted to actively promote growth in electricity demand. They thus focused almost exclusively on the supply side, on building ever more generating capacity. There was little attempt to curtail demand growth, apart from during short-term crises. Although there have been recent calls for greater demand-side management, this has had little impact on how the electricity authorities see their role. This supply-side focus has lead to a dominant perception about what constitutes a power station: they should be predictable, controllable, centralised and increasingly larger over time. Base load would be supplied by low-cost generators running continuously with approximately constant output, and peak load would be supplied by flexible and controllable generators such as hydro and natural gas plants. Over time, electricity supply and use patterns, electricity networks and electricity industry practices and operating standards have evolved around the characteristics of conventional generators.

The way that such established configurations, or 'technological regimes', are reinforced and thereby present a barrier to new technologies has been well documented, and measures have been proposed to create transition paths for new technologies. (For a historical case study on wind power in Denmark, see Kemp et al., 2001; for case studies in new sustainable transport initiatives see Hoogma et al., 2002.)

Wind power is expected to fit into the electricity configuration, which has developed around the technical characteristics of conventional generators. Yet wind power has quite different technical characteristics: it is intermittent, relatively unpredictable and diffuse. Electricity grids have been constructed to suit radial transmission from centralised generators; however, wind is decentralised and windy sites do not necessarily correspond with the locations of suitable existing grid infrastructure. The output of a wind plant is variable, and does not necessarily correlate with time of high demand.

Much debate over wind's technical capability has focused on the significance of its intermittency. The power output of a wind power plant fluctuates with changing wind speed. Large electricity systems typically have little or no storage capacity; thus supply and demand must be continually balanced. Wind power cannot be controlled, other than through wasting energy; thus if the wind drops, other generators must be available to meet the demand, and must alter their output to compensate for the fluctuations in wind output. This limits the amount of wind that can be installed on a grid, but these limits are dependent on the flexibility of other generators on the grid.

Given this intermittence, how should wind power be valued? The electricity industry uses 'capacity credit' as the measure of how much conventional generating capacity can be displaced by variable-output power stations without reducing system reliability. The typical position of the electricity authorities in the 1980s was that wind power was 'non-firm', with no capacity credit, and therefore equivalent capacity from conventional power stations was required as backup. Thus wind power's value was only the value of fuel savings – typically very low. Wind power advocates have long disputed this and have carried out many studies to show that wind power had a higher value to the system. During the early 1980s, members of AusWEA (described earlier) undertook such studies for Australia. They claimed that the electricity industry's assertion ignored the fact that conventional generators were not 100% reliable. They showed that at low levels of penetration, the capacity credit of wind power was about equal to its average output (Diesendorf and Martin, 1983).

In effect, the electricity industry analysed the value of wind power as an 'add-on' to an existing system; while the wind advocates argued that the systems should be analysed as a whole. But such arguments have carried little weight, partly because they are not in accordance with the actual operating practices in the electricity industry – where power stations are expected to be controllable, and available as required.

The electricity industry was re-structured in the 1990s, and the new rules of operation were built around the characteristics of conventional generators. Large generators are required to bid into the National Electricity Market, and the electricity system operator dispatches generators as required to meet forecast demand. The need to continually balance supply and demand has been unbundled from electricity generation and treated as an ancillary service, procured separately. Wind power does not fit into this model. Its output is dependent on the wind speed and varies continually. At low penetrations of wind power, the variation in wind power is barely discernable compared with the changes in demand. Thus while there have been only a few wind facilities in Australia, they have not been required to bid into the market. But, if the use of wind power were to grow significantly as the wind power industry expected under MRET, the variability of wind power may become a challenge for how the electricity market operates, and is thought to substantially increase the requirement for ancillary services.

Dealing with the variability of wind is of course an issue being faced in other countries where the penetration of wind power is also increasing. However, not all overseas experiences are directly transferable. Australia is very large with a low population density. Compared with the strongly interconnected electricity systems of North America and Europe, Australia's electricity system is relatively small; many areas are serviced by long, weak grids and most interconnectors between regions are relatively weak. These problems are coming to the fore in SA. Given its excellent wind resource, this is where wind farm developers have shown the most interest. Some of the windiest areas are serviced by grids that cannot support large inputs from wind farms. Moreover, SA's interconnection with neighbouring states is weak and designed mainly for imports rather than exports.

Given the conservative nature of the electricity industry and overriding concern to maintain security of supply, it is likely that the electricity system and network operators would have proceeded cautiously in allowing more than a small contribution of wind power. However, MRET unleashed a rapid growth in wind power developments, leaving the electricity industry seeking to control the situation and find a way that wind power can be made to 'fit' into the existing system. The electricity industry hopes that wind forecasting can partially reduce some of the challenges caused by wind power's variability: this is currently under investigation in Australia. As yet, there is no thought of how electricity systems can be redesigned to allow for a high penetration of wind power.

6 Conclusion

This paper has put forward a contextual historical approach combined with interpretive approaches to provide a more comprehensive account of the history of wind power in Australia. While this framework does not cover the whole story of wind power, it draws out elements that, though often implicit, are rarely analysed explicitly. A key strength is that it addresses the changing socio-political visions associated with wind power (Jørgensen and Karnøe, 1995) and how the support base for wind power has evolved with changing discourses about environmental technologies. The framework also addresses how the characteristics of an existing system shape how the 'efficacy' of new technology is judged. Such a framework could also be applied to analysing the history of other environmental technologies.

The purpose of this paper is analysis, rather than asking how to foster greater use of wind power. But many wind power advocates are particularly concerned with the latter question. The paper concludes with a reflection on the lessons of this study.

The current situation for wind power in Australia is uncertain. MRET provided a favourable period, albeit short-term. State government support for wind power and increasing international pressure on Australia to reduce GHG emissions may lead to its resurgence. History has shown how efforts to deploy wind power are crucially shaped by the institutional context and how periods of flux offer useful opportunities for intervention. Advocates of wind power have lobbied for an extension of renewable energy support mechanisms; but such mechanisms need not further the long-term success of wind power unless there is successful institutional change to enable wind power to achieve a better fit with the electricity industry. These support mechanisms are providing a short-term opportunity for wind power advocates to address institutional barriers to wind power, such as planning barriers and the rules of the electricity market. A recent project includes an analysis of how MRET is driving institutional change (see for example, Bunting and Healey, 2005). These efforts need to be continued, even as wind power faces a setback, to enable wind power to have a long-term future as new windows of opportunity arise.

References

Australia Government, Productivity Commission (2005) *The Private Cost Effectiveness of Improving Energy Efficiency*, Report No. 36, Canberra.

Australian Labor Party (1982) *Labor Profile: Minerals and Energy*. Melbourne: Labor Resource Centre.

Baumgartner, T. and Burns, T. (1984) *Transitions to Alternative Energy Systems: Entrepreneurs, New Technologies and Social Change*. Boulder: Westview Press.

Bijker, W. (1995) *Of Bicycles, Bakelites, and Bulbs: Towards a Theory of Sociotechnical Change*. Cambridge, MA: MIT Press.

Blakers, A. (1984) 'Windpower – too costly?', *South Wind*, Vol. 14–15, pp.13–14.

Blakers, A., Crawford, T., Diesendorf, M., Hill, G. and Outhred H. (1991) *The Role of Wind Energy in Reducing Greenhouse Gas Emissions*. Canberra: Department of the Arts, Sport, the Environment, Tourism and Territories.

Bunting, A. and Healey, G. (2005) 'Australia's mandatory renewable energy target: driver of institutional change?', Paper presented in the Proceedings of the *World Renewable Energy Congress*, Aberdeen.

Burningham, K. and Cooper, G. (1999) 'Being constructive: social constructionism and the environment', *Sociology*, Vol. 33, pp.297–316.

Commonwealth of Australia (2004) *Securing Australia's Energy Future*. Canberra: Commonwealth of Australia.

Cotgrove, S. (1975) 'Technology, rationality and domination', *Social Studies of Science*, Vol. 5, pp.55–78.

Diesendorf, M. and Martin B. (1983) 'Optimal generation planning for electricity grids containing wind farms', Paper presented in the Proceedings of the *Solar World Congress*, Perth, pp.2323–2329.

Hajer, M. (1995) *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process*. Oxford: Clarendon Press.

Hård, M. and Jamison A. (1997) 'Alternative cars: the contrasting stories of steam and diesel automotive engines', *Technology in Society*, Vol. 19, pp.145–160.

Heymann, M. (1999) 'A fight of systems? Wind power and electric power systems in Denmark, Germany, and the USA', *Centaurus*, Vol. 41, pp.112–136.

Hirsh, R. and Serchuk, A. (1996) 'Momentum shifts in the American electric utility system: catastrophic change – or no change at all?', *Technology and Culture*, Vol. 37, pp.280–311.

Hoogma, R., Kemp, R., Schot, J. and Truffler B. (2002) *Experimenting for Sustainable Transport: the Approach of Strategic Niche Management*. London: Spon Press.

Industry Commission (1991) *Costs and Benefits of Reducing Greenhouse Gas Emissions*. Canberra: AGPS.

Jamison, A. (2001) *The Making of Green Knowledge*. Cambridge: Cambridge University Press, Cambridge.

Jørgensen, U. and Karnøe, P. (1995) 'The Danish wind-turbine story: technical solutions to political visions?', in A. Rip, T. Misa and J. Schot (Eds), *Managing Technology in Society: The Approach of Constructive Technology Assessment*. London: Pinter.

Kemp, R., Rip, A. and Schot, J. (2001) 'Constructing transition paths through the management of niches', in R. Garud and P. Karnøe (Eds), *Path Dependence and Creation* (pp.269–299). New Jersey: Lawrence Erlbaum Associates.

Lovins, A. (1977) *Soft Energy Paths: Towards a Durable Peace*. San Francisco, and Ballinger, Cambridge (MA): Friends of the Earth.

Mercer, D. (2003) 'The great Australian wind rush and the devaluation of landscape amenity', *Australian Geographer*, Vol. 34, pp.91–121.

Mullett, L.F. (1957) 'Surveying for wind power in Australia', *Journal of the Institution of Engineers, Australia*, March, pp.69–73.

Russell, S. (1993) 'Writing energy history: explaining the neglect of CHP/DH in Britain', *British Journal of the History of Science*, Vol. 26, pp.33–54.

Schuck, S. (1991) 'Renewable energy technologies – an ECNSW perspective', Paper presented in the Proceedings of the *Electric Energy Conference 1991: Power for Developing Areas*, Darwin, 10–13 June, pp.34–38.

Schumacher, F. (1973) *Small is Beautiful: a Study of Economics as if People Mattered*. London: Blond & Briggs.

Senate Select Committee on South West Tasmania (1982) *Hansard*, Australian, Parliament. AusWEA submissions were those from Outhred, Blakers and Diesendorf.

Sismondo (1993) 'Some social constructions', *Social Studies of Science*, Vol. 23, pp.515–553.

South Australia, Advisory Committee on Future Electricity Generating Options (1984) *Possible Contribution of Alternative Energy Sources to Electricity Supply in South Australia Before the Mid 1990s*, Adelaide.

State Electricity Commission of Victoria (1989) *The SEC and the Greenhouse Effect: a Discussion Paper*, Melbourne.

State Electricity Commission of Victoria & Victorian Solar Energy Council (1987) *Wind Monitoring Study: Final Report*, SECV, Melbourne.

Verheul, H. and Vergragt P. (1995) 'Social experiments in the development of environmental technology: a bottom-up perspective', *Technology Analysis and Strategic Management*, Vol. 27, pp.315–326.

Victoria, *State Electricity Commission Act 1958*.

Victoria, *State Electricity Commission (Amendment) Act 1982*.

Weale, A. (1992) *The New Politics of Pollution*. Manchester: Manchester University Press.

Carbon capture and storage: settling the German coal vs. climate change dispute?

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Abstract: Carbon Capture and Storage (CCS) is an innovation that promises to enable the low Greenhouse Gas (GHG) emissions coal power station. However, the technology is still under development and issues such as economic viability, environmental safety, public acceptance and system integration remain unresolved at present. We analyse the viewpoints and strategies of major political and economic actors towards CCS and the future of coal in the German electricity system. We portray the actor constellation and try to determine the potential changes caused by CCS. We argue that, since CCS is still an emerging technology, viewpoints and strategies are characterised by many uncertainties at the moment. Actors are still trying to learn about CCS and are still forming their opinions. This opens up space for dialogue and moderates confrontation. A possible policy option that may result is the use of coal with CCS as a bridging technology towards a sustainable or even fully renewable energy future.

Keywords: actor constellation; Carbon Capture and Storage; CCS; coal; electricity; lignite; network analysis.

Reference to this paper should be made as follows: Fischer, C. and Praetorius, B. (2008) 'Carbon capture and storage: settling the German coal vs. climate change dispute?', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.176–203.

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1 Introduction

Coal is Germany's major domestic energy resource and electricity generation input. The country is a major lignite producer, while hard coal mining has declined in favour of imports. Altogether, coal provides almost 52% of the fuel inputs for electricity generation. Under business as usual conditions, this picture is unlikely to change in the near future.

With regard to sustainability, the extraction and combustion of hard coal and lignite for electricity generation is a heatedly debated issue. Coal proponents claim that coal use ensures security of energy supply at low cost. Under the conditions of a nuclear phase-out, they see no alternative to it. Environmentalists argue that coal mining and combustion are responsible for landscape destruction and that they threaten the earth's climate more than any other single energy source.

Carbon Capture and Storage (CCS) could be considered to be an innovative approach to these issues. CCS promises to enable the low-emissions coal power station. However, the technology is unlikely to be available before 2020, and it remains unclear at what cost. Also storage capacities are limited.

The innovation of CCS takes place in a special socio-technical context: The electricity system can be characterised as a 'Large Technological System' (Hughes, 1983). Such a system is composed of an enormous set of technical and non-technical components, all interconnected both horizontally and vertically. Unsurprisingly, such a complex system involves a high degree of inertia and barriers to change on all levels – technology, institutions and in particular actors. Such a system allows for incremental innovations a best. Correspondingly, fossil fuel-based electricity generation benefits from a long-standing, specialised and pervasive network of proponents, holding enormous technological, economical and knowledge assets, thus hindering the innovation and diffusion of new carbon-free technologies. Prospects for escaping this 'carbon lock-in' are unfavourable at present (Unruh, 2000; Perkins, 2003; Unruh and Carillo-Hermosilla, 2006).

CCS could be an innovation that paves the way out of the lock-in situation. At first glance, it is an incremental innovation, representing a change *within* the existing system that does not endanger (or that even reinforces) its overall structure. CCS allows for the continued use of fossil fuels; it can be combined with the existing infrastructure (that is, large-scale centralised power plants) and implemented by existing actors. Opponents therefore fear that CCS may further delay the urgent transition to a carbon-free electricity system. But in the long run, CCS could be an innovation that 'buys time' for radical restructuring and serve as a bridging technology towards a sustainable energy future.

Hence, two questions emerge. First, will CCS stand a chance to be implemented at all? Secondly, if it is implemented, where will its implementation lead? Which policy choices will be associated with CCS? Which place in the overall electricity system will it occupy? Will it be used to prolong the fossil fuel system, or to provide a bridge towards a low-carbon future?

In our understanding, answers to these questions depend heavily on the system of actors that generates energy policy choices. There is much agreement in political science on the fact that in modern societies, policy outcomes are determined by the interaction of a number of individual and collective societal actors, each with their respective interests, values and power resources. These actors establish more or less strong, durable or cooperative ties and channels for the information and resource exchange between them, forming webs that (depending on the theoretical outlook) might be labelled as 'sub-governments', 'policy communities', 'advocacy coalitions', 'policy networks' or 'issue networks'. State agencies and politicians are but one in this web of actors and often not the decisive one (Marsh, 1998).

With respect to CCS, apart from a – limited – R&D programme, no elaborated policy exists in Germany so far. Rather, the process is in the agenda-setting phase where issues for discussion and, potentially, decision-making are brought to the fore. We contend that, in this phase, identifying the relevant actors and determining their interests, visions and resources as well as the ties and interactions between them, will help to understand and delimit possible courses a future policy may take.

Hence, our paper sets out to explore whether the emergence of CCS technologies changes the political agenda for the future German coal-to-electricity system. Does CCS availability bring new policy and system options to the fore? Which of them can gain political support? Special attention is given to the future of coal, to the integration of coal and CCS into the future energy system as a whole, to the desired political instruments and framework for shaping future electricity policy and to timing aspects.

For this purpose, we portray the actor constellation in the German coal-to-electricity system. We identify the setting, interests and views of the actors, networks and coalitions in this policy field. Subsequently, we analyse the possible changes in the constellation that may result from CCS availability.

Though discussions decisions on CCS are of course embedded in an international context (markets for coal and CCS technology, information flows, international technological development, EU policies), our analysis focuses on the national actor system. Even today, core energy policies and other policies relevant for CCS (such as R&D funding, environmental regulation or allocation of emission rights) are decided upon on a national level. Investment decisions are made in the light of national policies and energy needs. It seems therefore sensible to choose the national actor system as the unit of analysis. EU policies, international markets, cooperation and communication channels are taken into account as far as they form a relevant framework for national actors' strategies and interests.

The core methodical challenge in such a task is to identify the relevant actors. To do so, we combined three approaches. First, an *institutional* approach points to the actors that are assigned formal roles in the policy-making process. These comprise not only the actors involved in legislation and programme-making, namely ministerial departments and parliamentary actors, but also various consultative bodies set up by the government. Secondly, an *interest-based* approach identifies all organised societal actors that might be affected by the respective policy and therefore can be expected to release lobbying efforts and stimulate the public debate. Thirdly, a *relational* approach consists in asking actors already identified about which other actors they view as important in the respective policy area. This way, we could establish a consistent set of relevant actors. (See Jansen, 2003, Ch. 4, for details on network identification.)

We based our research on written documents, observation and 29 interviews. Written documents included newsletters, published position and discussion papers, websites and journals of relevant actors as well as public speeches that were documented in the above media or available on demand. In addition to the information collection from publicly available sources, all actors were asked to provide relevant written material expressing their positions or activities. Observation meant the participation in three workshops organised by the Wuppertal Institute, BP and the Green Party, in which a number of actors were present and have given their views. Interviews were conducted personally, on the telephone, or in a few cases via e-mail[1]. Issues included the interviewees' assessment of the chances and risks of CCS, their goals and activities in this field, their forecasts and wishes for a future electricity system (especially the role of coal and of CCS within it), their requirements for a political framework for coal and CCS, their assessment of relevant actors in the field of CCS and their communication and cooperation or conflict with other actors.

The main analysis was conducted in summer 2005. In autumn/winter 2005, the draft paper was communicated to the actors interviewed, and some provided comments that were included in the final version. In autumn 2006, we did another literature research, reviewed current developments and updated the paper, where necessary.

Section 2 summarises the major features of CCS and outlines the resulting questions and challenges that actors are facing when discussing CCS and coal. In Section 3 we provide a detailed description of the actor constellation, followed by a concluding discussion in Section 4.

2 Coal and CCS: what are the issues at stake?

To date, CCS is at an early stage of development and market formation, leaving several decisions to be made and a number of questions to be asked. This section gives a brief overview of the current state of CCS technology, its economics and its environmental performance. From this, we procure some issues coming up in the debate about a future deployment of CCS. A detailed assessment of the current status of CCS is presented in the recent IPCC report (IPCC, 2005).

2.1 CCS characteristics

The technologies and practices associated with carbon capture and geologic storage have been in commercial operation within various industries for 10–50 years (Curry, 2004). The oil industry, for example, has been injecting CO_2 into oil formations to recover additional oil since the 1970s (so-called Enhanced Oil Recovery or EOR). A network of pipelines was built in the Western USA in order to connect CO_2 emission points and oil drilling places. One of the main differences between EOR and CCS is that the former is not concerned about the long-term fate of the injected CO_2. Leakage is, therefore, not an issue and neither is liability. R&D is thus needed on its technological integration into the electricity generation process and particularly on leakage and storage issues.

2.1.1 Technology

In electricity generation, CCS is possible for a number of fuel inputs. However, due to differences in fuel prices, the debate has been focusing on CCS from coal-based power plants; it is not likely to be economic in gas plants. Several CCS processes are currently being developed: capture from the flue gas (*post-combustion*), separation from the fuel gas (*pre-combustion*) and *oxyfuel technology*, in which the fuel is combusted with pure oxygen, producing a high concentrate of CO_2 that facilitates its recovery. Post-combustion is available for conventional power plants, pre-combustion is applied in Integrated Gasification Combined Cycle Plants (IGCC). Retrofit is only possible for post-combustion. Technologically and economically, IGCC appears to be the most promising (Watson, 2005; Radgen et al., 2006). In Germany, the first 30 MW oxyfuel pilot plant is being conducted by the energy utility Vattenfall, and is to be completed by 2008 and then followed by a demonstration station of 200 MW. RWE announced, meanwhile, that they are to build an IGCC plant of 450 MW by 2014.

2.1.2 Transport and storage

The captured CO_2 can be compressed and led through pipelines or by ships or other carriers to the storage site in, e.g. saline aquifers, oil and gas fields or coal seams. The disposal of CO_2 in deep oceans is currently not regarded as an option in Europe, including Germany.[2] Its risks, particularly in terms of the time of storage and effects on the marine environment, are considered to be too high (WBGU, 2003).

In Germany, saline aquifers have the greatest storage potential. The total theoretical storage capacity in Germany is estimated to be in the range of some 80–150 years, if all CO_2 from power plants (about 320 Mt/a) is to be stored (COORETEC, 2003; GESTCO, 2004). Actual technical and economical capacities are lower, depending on geological restrictions, cost and the location of the storage sites. Moreover, as many storage sites are cross-national, the distribution of rights and responsibilities requires clarification.

2.1.3 Leakage and the energy penalty

The major environmental risk (and perversion) of CO_2 storage is leakage. Model calculations and natural analogies suggest that in many geological formations, leakage rates below 1% over 1,000 years are possible. Exhausted gas and oil fields and, to a lesser extent, salt caverns have been so far regarded as safe permanent storage sites. However, any leakage rate greater than zero means that most of the CO_2 stored will have escaped some day. Therefore, liability for expected or unexpected leakage is an issue to be debated. Doubts about storage safety have been fuelled by a recent US study showing that stored CO_2 can dissolve minerals in the ground and, by this means, cause leakage (Kharaka et al., 2006).

The second major drawback of CCS is its negative impact on power plant efficiency. For conventional hard coal plants, the conversion efficiency decreases between 8 and 12% points, for IGCC between 6 and 8% points (Schumacher and Sands, 2006). This figure increases even more when a Life Cycle Analysis (LCA) of all up- and downstream processes is conducted (Idrissova, 2004; Pehnt, 2005). Both – leakage and conversion efficiency – are significant parameters for the global warming balance of CCS. Efficiency losses also increase fuel consumption and associated environmental damage such as landscape destruction and pollutant emissions.

2.1.4 Economics

The market potential for CCS depends mainly on how economical the process is compared with other CO_2 reduction strategies (DIW, 2005). Carbon capture increases the cost of coal-based electricity generation because of the additional plant equipment and the 'energy penalty'. The latter is smaller for pre- than for post-combustion processes, with corresponding economic effects. In the relevant literature the range of estimated costs is great, depending on the underlying assumptions, in particular those on investment costs, conversion efficiencies, future interest rates, fuel prices and the cost of CO_2 emission certificates.

Due to the comparatively high cost of retrofit, CCS is more likely to be implemented in new power plants once it is commercially available. CCS could be economically viable at a CO_2 price in the range of 30 to about 50 EUR/t. For conventional hard coal plants, CCS would increase the costs of electricity generation by about 3–4 cents (EUR) per kWh; for IGCC the increase amounts to about 2–3 cents. At a carbon prize range of 25–35 EUR/t $CO_{2,}$ renewable-based electricity production can compete well with CCS (Schumacher and Sands, 2006; based on IEA, 2004; WI et al., 2004a). This is in accordance with the estimations of IPCC (2005).

Thus, whether CCS will make economic sense first and foremost depends on the existence and level of carbon prices and the corresponding climate policy goals. The degree to which it will be able to compete with renewable energy sources remains an open issue. In any case, commercial availability is not expected any earlier than 2020, and CCS will be most competitive for large, centralised power plants, ideally located close to the storage location. Correspondingly, the economic potential of CCS to contribute to climate change mitigation remains limited to the share of electricity generated centrally.

2.2 Resulting challenges

In the face of the above features, actors involved in the debate about the future role of coal and CCS for electricity generation in Germany are confronted with numerous issues. In short, two separate but interlocking concerns can be distinguished: first, the potential impact of CCS on the future electricity system, and secondly, the policies to shape the path towards the future.

2.2.1 Potential impact on the future energy mix

A first question is in which direction CCS will affect the absolute and relative shares of lignite and hard coal. On one hand, coal may benefit from the reconciliation of coal combustion and climate policy that CCS promises. On the other hand, CCS costs might negatively impact on coal's competitiveness. Both depend on the development of the price for CO_2 emission certificates.

Secondly, CCS might affect the degree of centralisation of the future system: as it is only feasible for large point sources of emissions, it may be at odds with a more decentralised structure of renewable technologies. A related pressing concern is whether CCS might be implemented in such a way that it functions as a 'bridge' instead of hindering other sustainable technologies, e.g. renewables, from diffusion into the existing system. Similarly, the question arises how to synchronise CCS with the investment cycle for power plants. CCS will probably not be available before 2020. Observers expect that by this time some 40 GW of capacity will already have been replaced in Germany, due to the expected phasing-out of nuclear energy and the decommissioning of further plants (Matthes and Ziesing, 2003, p.13f; Umweltbundesamt, 2003, p.10). Retrofit is less cost-effective than integrated CCS, and is not considered an attractive option. The question is, therefore, whether CCS will simply come too late.

2.2.2 Policy options and needs

A variety of policies and measures would need to be introduced if CCS is to be developed technologically and supported in its market introduction. Among the most debated issues are the level and intensity of public R&D funding for CCS as compared with other (renewable) energy or climate change mitigation technologies, and the regulatory framework needed for safe storage. Above all, climate policy builds the framework for any activity and impacts on the economic performance of CCS via the resulting carbon price. Also, international diffusion of CCS depends on its inclusion in the portfolio of technologies accepted for the flexible instruments of the Kyoto Protocol (JI and CDM).

2.2.3 Public acceptance

In addition to these concerns, public acceptance is the great unknown at the moment. A major fear articulated by potential investors is that the storage of CO_2 may trigger an avalanche of public protest activities, similar to those observed in the case of nuclear energy. This aspect will be treated in more detail in Section 3.1.4 later.

3 Coal and CCS: changing actor constellations?

CCS is still in an early stage of development, a fact that finds its reflection in the structure of actors involved in this area. Globally, more than 60% of actors involved in CCS are situated in research institutes and universities. In Germany, about two thirds belong to R&D institutions, with the remaining one third stem from industry (Radgen et al., 2006). In the following sections, we discuss the setting of actors involved in developing and implementing CCS. Based on our interviews, we provide an overview of their interests and positions. First, we describe the actor constellation. We will then summarise which lines of consensus or dissent emerge in issues that are of particular interest to actors. Finally, we assess whether the discussion about CCS brings about changes in the constellation that may affect the future of coal.

3.1 The actor constellation in Germany

3.1.1 CCS activities

The past few years have witnessed a growing level of activities around CCS, both nationally and internationally (Radgen et al., 2006; Linßen et al., 2006; European Commission, 2004). In Germany, most activities focus on R&D, with the electricity utilities Vattenfall and RWE as the only actors with actual investment plans to date. In its current energy research programme, the Federal Ministry for Economics and Technology (BMWI)[3] supports R&D in CCS and power plant efficiency with a input of EUR 284 million from 2005 to 2008. The programme is based on the COORETEC (CO_2 Reduction Technologies) concept developed by the ministry in cooperation with industry and science (BMWI, 2005, pp.24–27; BMWI, undated). The Federal Agency for Geosciences and Raw Materials (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR) is involved in 13 projects on storage possibilities and storage safety. In September 2005, the Federal Ministry of Education and Research (BMBF) national programme, 'CO_2-Storage in Germany', in the framework of the R&D-Programme GEOTECHNOLOGIEN. It includes ten research projects, worth almost EUR 8 million altogether, treating different aspects of storing CO_2 underground (Stroink, 2006).[4] Almost 6.7 million is provided by the BMBF, 1.3 million by the participating firms.

While these programmes focus on technological R&D, the Federal Ministry for the Environment (BMU) is running a more policy-oriented project for evaluating CCS and comparing it to renewable energy technologies from a climate-policy perspective. The programme includes a dialogue between different actors by means of a number of workshops (WI et al., 2004b). The Federal Office for the Environment, the central scientific body of BMU, also assessed CCS technologies (Radgen et al., 2006) and formulated a position paper, concluding that CCS could, at the utmost, be considered a bridging technology (Umweltbundesamt, 2006). However, compared with other research topics, and even to renewable energy, CCS today accounts for only a small share of total energy R&D expenditures (BMWI, 2006).

Furthermore, European initiatives are an important framework for German activities. On the European level, R&D in CCS has been increasingly supported by EUR 16 million within the 5th EU Framework Program for Research (FP) and by EUR 70 million within the 6th FP (Dimas, 2006a).[5] On 1 December 2005, the European Commission in cooperation with major industrial associations launched the Technology Platform for Zero Emissions Fossil Fuel Power Plants (ZEFFPP, later ZEP).[6] It brings together actors from industry, research, NGOs and the European Commission in an effort to develop a 'Strategic Research Agenda' and 'Strategic Deployment Plan' for CCS as an input to the 7th FP (European Commission, 2006). In fact, one of the priorities announced for the 7th FP are the 'Zero-emission power plants' and the research, development and demonstration activities connected to these plants (Dimas, 2006a, b). Besides, Germany has been engaged in the Carbon Sequestration Leadership Forum (CSLF), a ministerial-level international initiative for CCS development, since 2003.

3.1.2 Overview of actor groups

Most of these activities are rather recent. For a long time, CCS had not been much of a political issue in Germany. The debate had been taking place in expert circles, involving a relatively limited set of actors. The main drivers were research organisations, the oil and gas industry and a few political bodies such as the Federal Ministry for the Economy and Technology (BMWI) and the German Council for Sustainable Development. The oil and gas industry, albeit not directly involved in electricity generation, has longstanding expertise in using CO_2 for EOR and would benefit from CCS with a double dividend: first, by receiving CO_2 for EOR and, secondly, by selling off the related CO_2 certificates.

Now the time seems ripe for more actors to join in. In the face of rising oil and gas prices, recent turbulences about Russian gas supplies, and a new centrist government seeking to coin its own profile in energy policy, energy security is on the agenda again. The Chancellor herself invited stakeholders to an 'Energy Summit' on 3 April 2006. At the same time, climate policy is re-emerging as an issue: the negotiations for the second commitment period of the Kyoto Protocol are beginning, climate has been a topic at G8 summits, and recent flood events have heightened public attention. And finally, CCS technology is making progress and is being recognised on an international level by the climate policy community, as shown by the recent IPCC report on the issue (IPCC, 2005). In this vein, political interest in CCS is beginning to increase and the debate has been gaining considerable momentum lately.

This is especially so in the case of electricity and power plant industry and environmental NGOs. For some time, electricity and power plant industry had shared a pattern of arguments with coal mining industry, called the 'Three-Step' or 'Three Horizons' concept. It stipulated that fossil fuels should be made more climate-friendly in three steps: first, apply existing 'best practice' technology (and export it worldwide); secondly, develop new power plants with increased conversion efficiency; and thirdly, explore possibilities for CCS. CCS was thus presented as a technology for the rather remote future. The main reason behind this reluctance was the expected loss in conversion efficiency and increase in cost. Industry was involved in R&D activities in order to keep up-to-date but kept its engagement rather low key, called for public funding as a condition for an own investment, and did not do much to publicly promote the technology.

With rising natural gas and the possibility of carbon prices also rising, CCS is slowly becoming more attractive. The three biggest electricity companies, E.on, RWE and Vattenfall, and the power plant constructor, Siemens PG, now have key roles in the EU Technology Platform on Zero Emissions Fossil Fuel Power Plants (ZEFFPP/ZEP). They are also involved in a number of projects within the GEOTECHNOLOGIES Programme. Ten months after Vattenfall announced the construction of an oxyfuel demonstration plant in May 2005, RWE outplayed them in March 2006 by announcing the construction of an industrial-scale IGCC plant with CCS. The 'Three-Step' concept is still used in public communication, but is being modified to endorse CCS in a more committed fashion.[7]

One might expect that prospects for international markets stimulate electricity industry's activities. This is also voiced by some interview partners, pointing, for example, to China's future energy need and its expected rise in the use of coal. However, the factual level of commitment seems to be dominated more by national considerations:

it neatly corresponds to the share of coal-based generation in electricity companies' German portfolio. Vattenfall Europe, initiator of the first publicly visible project, generates some 77% of its electricity from domestic lignite (Vattenfall, 2004, p.6). RWE Power, which followed, has a share of 66% (hard coal 26%, lignite 40%) (RWE, 2006, p.116). E.on, which has not yet issued its own project but is engaged in R&D cooperations, had a share of 48.8% in 2004 (26.1% hard coal; 22.7% lignite) (E.on, 2005, p.40). EnBW, which has no profile in the issue, does not disclose its coal share but does have only a 23.8% share of fossil fuel generation, including oil and gas (EnBW, 2005, p.111). International markets seem to be more of a theoretical argument, since the biggest future coal users (like China) do not have climate commitments so far and it remains an open question to what degree they will be interested in climate technology.

Within power plant industry, interest is also accruing. ALSTOM wants to develop a capture method for the oxyfuel process, while Siemens is focusing on IGCC technology. However, they feel that there are uncertainties because they essentially depend on the decisions of electricity industry.

Environmental NGOs have also been making up their minds recently. As of summer 2005, only Germanwatch, Greenpeace and WWF had adopted a clear position. Recently, they were followed by Friends of the Earth Germany (BUND) in February 2006 and by the Climate Action Network (CAN), a European network that includes a number of German NGOs, in October 2006. The Nature Protection League (NABU) has formed a position but not in written form so far. In the face of the rather complex issue, NGO positions have become more diverse as the discussion has gone on.

The general tendency is to formulate quite stringent pre-conditions for CCS use and to strictly prioritise renewable energies and energy efficiency over any fossil fuel source, while admitting (or at least implying) that CCS might be a possible emergency or bridging option to protect the climate in case other attempts fail and the pre-conditions are fulfilled. Germanwatch and NABU express most clearly that CCS might even be desirable and demand that every new coal plant in Germany should be equipped with CCS or prepared for retrofit. Germanwatch argues that CCS might be the only solution for rapidly industrialising countries. On the other side of the spectrum, BUND clearly rejects CCS. The organisation fears that CCS might be used to prolong fossil fuel use with all its negative environmental effects and sees it as a 'fig leaf' for coal industry.

The latter is, surprisingly, remaining rather passive. Associations that represent traditional coal and lignite mining industry (like DSK, GVSt or DEBRIV), as well as electricity generators who rely on coal (like STEAG), have not been strongly promoting CCS. Some even refused to comment on the issue. In publications, they endorse the above-mentioned 'Three-Step' concept. From our interviews, some possible reasons emerge: first, in the case of hard coal, it is a question of task sharing between coal miners and traders on one hand and electricity industry on the other hand. Mining industry leaves it to power industry to deal with an issue that is ultimately so closely related to power generation. Secondly, climate protection has never been much of an issue for mining industry. Their main arguments for an extended use of coal revolve around its easy availability and the security of supply that it promises to deliver. Finally, CCS creates additional costs for power generation from coal, which may undermine its competitiveness.

While electricity and power plant industry as well as NGOs have become more active, other groups of actors remain essentially silent. The issue is only slowly moving into debates within parties or in parliament, and only recently parties start to articulate active positions. In April 2006, for example, the CDU/CSU suggested CCS to be a major focus of their initiative 'ZukunftEnergieForschung' (Future Energy Research) (Donner and Lübbert, 2006). Positions in the Green party, as articulated in interviews and during a workshop organised by the party in early December 2006, more or less mirror the spectrum within the environmental movement: they range from very critical to some interest with slight reservations. A first minimum consensus was reached in a resolution from 6 November 2006, where the party declares that future investments in coal-fired generation plants should only be approved when they apply CCS (Grüne, 2006). Social Democrats, traditionally attached to coal industry, would like to reconcile coal use and climate protection (which might be one of the reasons why the SPD-led BMWA has been pushing the case) and target at the emissions-free power station. Liberals and Socialists have no strong case yet, with the latter being rather sceptical while the Liberals support R&D initiatives.

Like the majority of the parties, trade unions are remaining on the back seat. Although the debate has been accelerating, CCS has thus not yet completely left the expert circles and entered the realm of public debate. Table 1 very briefly summarises the actor groups engaged in CCS policy in Germany. Based on an in-depth analysis of selected organisations from each group, it shows the strategic interests, general attitudes and activities of different actors with respect to CCS.

3.1.3 Influence of actors

To determine which actors are influential, we assessed their resources and the linkages between them. By linkages we mean communication, cooperation and exchange of financial, informational or human resources. Actors who provide others with resources are generally more influential than resource-dependent actors. Also, cooperation generally increases influence; communication channels can also be an important source of influence for otherwise resource-poor actors.

The interesting thing about CCS is that different types of resources are unevenly distributed across actors. *Industry* (including electricity, power plant and oil and gas industry) possesses substantial funds and the formal power of decision-making on investments. On the other hand, due to the uncertainties related to CCS, industry depends on *researchers* to provide vital information and on *policymakers* to reduce the financial risk by constructing a calculable policy framework and providing additional R&D funds. Within the political system, *ministries*, due to their specialised bureaucracy and the lesser degree of politically motivated controversy, generally have significantly more time, knowledge and human resources at their disposal to draft policies than parliament or parliamentary parties have.

NGOs and *counselling bodies* have in common that they neither possess formal decision-making power whatsoever nor possess any significant funds. However, they command one powerful resource: legitimacy. NGOs and counselling bodies are heard in the public debate, because they are assumed to have no economic self-interest in the issue. Industry representatives interviewed in our study are well aware of this fact, consistently articulating concern that NGOs may launch a public debate on safety or environmental issues, stifling acceptance for CCS. The case of nuclear energy is often cited as a disconcerting example.

Table 1 Actor groups in the CCS policy process

Actor group (and showcase examples analysed in this study)	*General attitude*	*Basic interest / concern*	*Activities*
Environmental organisations Climate Action Network (CAN), Bund für Umwelt und Naturschutz Detschland BUND (Friends of the Earth Germany), Germanwatch, Greenpeace, World Wide Fund for Nature (WWF), Naturschutzbund NABU (Nature Protection League)	Mixed generally critic	CCS as potential climate protection back-up option, but high risks: 'fig leaf' for prolonged coal use; environmental and safety issues, competition for R&D with renewables. Rebuttal of ocean storage. But open to dialogue, only a few reject CCS upfront.	Position papers, taking part in consultation processes, partly organising workshops.
Electricity Industry (power producers) Energie Baden-Württemberg EnBW, E.on, RWE Power AG, Vattenfall, Verband der Großkraftwerksbetreiber VGB Power Tech (Alliance of Large Scale Power Plant Operators)	Mixed; partly proactive; partly ambivalent	CCS as possible future option but many uncertainties and open questions with respect to cost and energy penalty. 'Three-step concept': investing in state-of-the-art plants is given priority, followed by increasing production efficiency, and in the last step, by CCS. Interest in CCS generally corresponds to share of coal-based generation.	Involved in R&D activities (COORETEC, GEOTECHNOLOGIES, ZEP). Generally making their own investment dependent on additional public funding. Vattenfall launches oxyfuel pilot plant, RWE plans to launch an IGCC industrial scale plant by 2014.
Coal Industry (other than power producers) Deutsche Steinkohle AG DSK, Gesamtverband der Deutschen Steinkohle, Deutscher Braunkohle-Industrieverband DEBRIV (German Lignite Industry Alliance), GVSt (General Alliance of German Hard Coal), RAG (former Ruhrkohle AG, Ruhr Coal Corporation), Deutsche Steinkohle AG DSK	Passive	CCS as possible future option but open questions with regard to cost and energy penalty. Climate protection not a major issue; focus on security of supply. 'Three-step concept' is partly shared. Tends to delegate the issue to electricity industry that seems more immediately affected.	Generally none; no explicit promotion.

Table 1 Actor groups in the CCS policy process (continued)

Actor group (and showcase examples analysed in this study)	*General attitude*	*Basic interest / concern*	*Activities*
Power Plant Industry ALSTOM, Siemens Power Generation	Ambivalent	CCS could be interesting business opportunity but many open questions. Share 'Three-step' concept. Commitment ultimately dependent on electricity suppliers' interest.	Involved in R&D activities (COORETEC, ZEP).
Oil and Gas Industry Shell, BP	Driver	Interested in CCS if applied in the exploitation of oil and gas fields. Various reasons: could help to comply with emissions-reduction obligations, economically attractive in the case of enhanced oil and gas recovery, chances for making commercial use of existing know-how.	Heavily involved in R&D, commercial projects, organising dialogue. Do not deal with capture from power plants – however, experience gained in storage could spill over to other sectors.
Renewable Energy Industry Bundesverband Erneuerbare Energien, BEE (Federal Alliance for Renewable Energies)	Ambivalent	CCS as possible complement to REG, no strong competition because REG is expected to become competitive but maybe competition for R&D funds.	None
Trade Unions Industriegewerkschaft Bergbau, Chemie, Energie (IGBCE) (Industrial Union for Mining, Chemicals and Energy), Vereinigte Dienstleistungsgewerkschaft, ver.di (United Services Union)	Broad spectrum, but as yet rather passive	Broad spectrum – IGBCE more positive, ver.di more negative. Do not feel very affected as of yet.	No public activities, internal discussions starting.

Table 1 Actor groups in the CCS policy process (continued)

Actor group (and showcase examples analysed in this study)	*General attitude*	*Basic interest / concern*	*Activities*
Research Institutes			
Regular Institutes Bundesanstalt für Geowissenschaften und Rohstoffe BGR (Federal Agency for Earth Sciences and Raw Materials), Fraunhofer Institut für System- und Innovationsforschung, ISI (Fraunhofer Institute for Systems and Innovation Research), Geoforschungszentrum Potsdam,GFZ (National Research Centre for Geosciences)	Driver, promoter of debate	CCS as possible bridging technology, more relevant globally than in Germany, many open questions to be solved, opens interesting areas for further research.	Research activities, taking active part in research programmes and cooperative projects (e.g. GFZ Coordinator for GEOSCIENCES).
'Green' Institutes Öko-Institut (Institute for Applied Ecology), Potsdam Institut für Klimafolgenforschung PIK (Potsdam Institute for Climate Impact Research), Wuppertal Institut für Klima, Umwelt, Energie, WI (Wuppertal Institute for Climate, Environment, Energy)	Ambivalent, promoter of debate	CCS possible option for climate protection, but needs careful comparison with other options and regulatory framework.	Research projects, stimulating dialogue.
Parliamentary Parties			
Christlich-Demokratische Union, CDU (Christian Democratic Union), Sozialdemokratische Partei Deutschlands, SPD (Social Democratic Party), Freie Demokratische Partei, FDP (Free Democratic Party), Bündnis 90 / Die Grünen (Green Party), Partei des Demokratischen Sozialismus, PDS (Party of Democratic Socialism)	Carefully supportive	Positions are held by specialists within CDU, SPD and Greens; no detailed positions are held by FDP and PDS. CDU tends to support it; Greens tend to be critics; SPD ambivalent. However, it is a complex issue of little public interest which does not encourage parties to much engage in it.	Partly internal and first stakeholder discussions; in declarations and programmes mostly supportive to R&D in 'clean coal'

Table 1 Actor groups in the CCS policy process (continued)

Actor group (and showcase examples analysed in this study)	*General attitude*	*Basic interest / concern*	*Activities*
Ministries			
Bundesministerium für Wirtschaft und Technologie, BMWi (Federal Ministry of Economics and Technology, former Federal Ministry of Economics and Labour)	Driver	Support for coal, export technology.	Energy Research Program based on program (COORETEC 2003).
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU (Ministry for the Environment, Nature Protection and Nuclear Safety)	Promoter of debate	Possibly necessary option for climate protection vs. environmental and safety risks, must be handled with care, societal debate necessary.	Funding research and dialogue project on CCS as compared to renewables (WI et al., 2004).
Bundesministerium für Bildung und Forschung BMBF (Federal Ministry of Education and Research)	Driver		Funding research on storage (GEOTECHNOLOGIES Programme).
Counselling Bodies and Agencies			
Sachverständigenrat für Umweltfragen SRU (German Advisory Council on the Environment), Nachhaltigkeitsrat (German Council for Sustainable Development), Wissenschaftlicher Beirat Globale Umweltfragen WBGU (German Advisory Council on Global Change)	Ambivalent; promoter of debate	CCS may reconcile coal and climate but should be used under environmental restrictions. Necessity of public debate, interest in promoting it.	WBGU, Nachhaltigkeitsrat issued recommendation, SRU currently discussing the issue, dena organised conference

The potential influence of counselling bodies is shown by the fact that the German Council for Sustainable Development's recommendation on coal with its support of CCS has been widely recognised and debated (Nachhaltigkeitsrat, 2003). Between these actors, we can find two closer-knit networks, linked by a looser net of communication and dialogue. The first network is formed among *electricity and power plant industry*, *oil and gas industry*, mostly technology-oriented *researchers*, the *BMWI* and *BMBF*. They cooperate mainly in developing, funding and executing R&D programmes and projects (like COORETEC, ZEFPP and GEOTECHNOLOGIES). *Coal mining and trading industry* is connected to this network, mainly via organisational links with electricity industry: miners and power producers are part of the same corporations and are grouped in the same umbrella organisations. The *trade union* 'Industriegewerkschaft Bergbau, Chemie, Energie' (IGBCE) also comprises sectors. Moreover, coal industry is also becoming engaged within the GEOTECHNOLOGIES Programme.

The second network is formed by the *environmental NGOs, BMU*, *the renewable energy lobby* and another part of the *scientific community*, mostly focusing on a socio-political, economic and/or socio-ecological approach. The network is mainly held together by information and consultation flows.

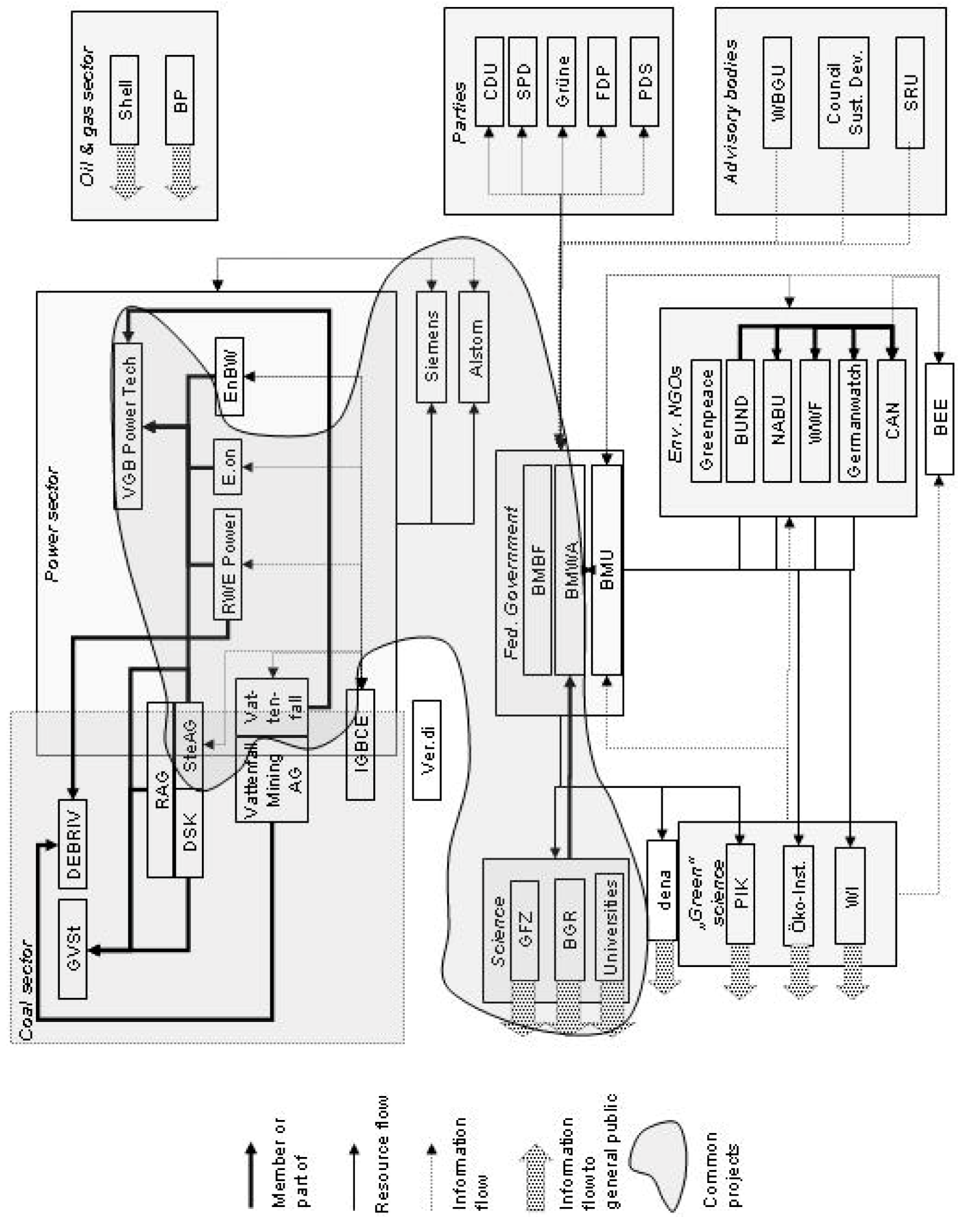
These two networks are connected via a looser network of communication. Ministries, electricity and power plant industry, researchers and NGOs at least know each other's positions from organised communication – for example, within ZEP, in CCS workshops organised by the mineral oil industry or in the context of the BMU research project (WI et al., 2004b). Coal mining industry, political parties and trade unions have, by contrast, taken part in such forums to a lesser degree.

Two ministries, BMU and BMWi, form a kind of 'hinge' between the two networks, linking them and at the same time highlighting what separates them. As parts of the same government, they are in regular dialogue and coordinate their activities. On the other hand, however, they compete for responsibilities and represent conflicting interests, which limits cooperation and information flows.

Parties and *consultative bodies* are currently not part of one of the closer networks (except for individual representatives). Parties are not yet very active in the issue. As for the consultative bodies, their role is to stimulate dialogue rather than to take sides in everyday politics. Figure 1 gives a simplified[8] portrait of the actors with their respective linkages.

To sum up, it is not easy to determine who are the most influential actors. For sure, power industry is a veto player. Without its investment decisions, CCS will not come about. However, there is no single, most important actor that could make CCS a reality or shape its course. Rather, we find an interdependence of a number of actors, each commanding different resources and profiting from different linkages. We can discern, though, a more central set of actors made up of industry, NGOs and ministries, from a more peripheral one made up of parties, counselling bodies, trade unions and the mining industry.

Figure 1 Actor network in the coal/CCS system



3.1.4 Public perception

The opinion of the (general and local) public on CCS is a white spot in the actors constellations as portrayed so far; yet it is an essential component of a successful deployment of CCS. In debates and interviews, reference is often made to the German anti-nuclear power movement in the 1980s, which caused substantial supplementary costs for securing building sites, delays in construction times, and sometimes even succeeded in completely preventing the construction of power stations.

Unfortunately, very little information about public acceptance of – or opposition to – CCS is available to date. Only a handful international studies have been conducted on public perceptions and acceptability (see Curry, 2004; Curry et al., 2005; IEA, 2004; Peteves et al., 2005; Coninck et al., 2006 for a comprehensive discussion), none of them on Germany. Most studies show very low levels of recognition of technology and related issues.

Major reasons found for this are the early stage of technology development, combined with a missing awareness of the underlying reason or the need for deploying it (global warming). In consequence, both the technology itself and the threat it is meant to combat seem remote and abstract. Shackley, McLachlan and Gough (2004) argue that the public does not have well-formed opinions on issues that are not of immediate salience or relevance to their everyday life and livelihood, a thesis that seems to apply to carbon storage. Opinions and perceptions on such 'remote' issues are shaped by the media and other marketing efforts of stakeholders. Very few reports on CCS or clean coal technologies were launched in the media so far, although the picture is slightly changing since the energy summit called in by the German chancellor on 3 April 2006. Just a few days beforehand, RWE announced to the public its plans to build 'the first CO_2-free power station'. Subsequently, newspapers run reports on the technology and its prospects; all of them, however, pointing to its early stage of deployment.

Curry (2004) and Curry et al. (2005) argue that public outreach activities will have to address global warming and the resulting need for CCS, if CCS is to be appraised positively by a broad public, in particular the local public at construction or storage sites. So far, such activities have been rather limited. However, an increasing momentum can be stated, with a growing number of activities and publications on both sides, the critical NGO and the proponents. Surveys and focus group studies on public attitudes and concerns are conducted, and organisations like the CSLF line up to 'promote awareness and champion legal, regulatory, financial and institutional environments conducive to such technologies'. On EU, national and international levels, tasks forces and meetings are formed with the objective to meet with all stakeholders including NGOs, and to develop 'road maps' that include broad public outreach strategies. NGOs, on the other hand, are now distributing their new position papers, their major concern being that CCS may be seen as a solution that would allow the continued use of fossil fuels as long as they are available (IEA, 2004, p.189).

At this stage, some first ideas about the public perception of CCS may be derived from the existing studies and position papers. Generally, two types of opposition to new technologies could be expected to emerge: First, opposition from stakeholders preferring other mitigation measures to CCS, and secondly, local opposition to specific projects and sites, notably storage (IEA, 2004). While the first type of opposition to CCS (some NGO, some representatives of non-fossil energies) is already about to form up, the broad and the local public are not yet involved in the discourse. In a survey in two UK cities, conducted by Shackley, McLachlan and Gough (2004), the public turns out to be uninformed and unsure about CCS. The initial reaction is sceptical and, after some information given to the participants, they 'slightly' support it, compared to clear support, e.g. for solar and wind power. Positive features attributed to CCS include the expectation that it 'buys time for other solutions' and that it helps to mitigate climate change. However, there are fears about leakage and possible damage to ecosystems. There is a perception that CCS is not yet being tested enough.

It is difficult to predict future public reaction. Experience from nuclear energy cannot be easily transferred, since nuclear energy imposes other risks than carbon storage. A few lessons can be drawn from experience and the few studies, and the current and planned activities of CCS proponents with respect to public acceptance reflect these insights. In particular, public acceptance and confidence are considered to pre-suppose an open and transparent discussion of the positive aspects of CCS, but also of its risks and the related uncertainty. Also, a proper site selection with public involvement (stakeholder processes) is believed to reduce public opposition. Furthermore, monitoring, verification and liability issues are considered to need credible treatment, in particular regarding leakage. Similar (and a few more) points are also being raised by the NGOs involved in the debate.

All in all, the public (together with the NGOs) is likely to respond with watchfulness to CCS (Hawkins, 2001). If CCS is communicated as a 'magic bullet', allowing policymakers to abandon all activities to foster efficiency and renewable energy, then the environmental community is likely to dissent, and local opposition to designated sites for CO_2 storage can be expected to boost.

3.2 Issues of the debate and potentials for consensus

In this section, we summarise the opinions expressed by our interviewees and written documents, sketching the main issues of debate and areas of agreement and dissent.

3.2.1 General attitude

One interesting finding is that there is a considerable degree of consensus on many topics across actors. Most remarkably, there is little fierce opposition towards CCS – though little enthusiastic support, either. The technology seems to promise interesting options for climate protection, but a number of uncertainties and risks remain. All sides agree, therefore, that it requires further scientific exploration and public discussion and all are willing to engage in such dialogue. It is also agreed upon that ocean storage is undesirable and that depleted oil and gas fields and saline aquifers are the most promising storage sites. CCS is furthermore conceived as an international issue that cannot, and should not, be decided on a national level. Future worldwide energy demand, the needs of newly industrialising countries, export options, foreign storage potential and international climate regimes will influence CCS and the development of coal.

3.2.2 Future electricity system

There is also moderate agreement on some *basic features of a future energy system* and on the role of coal and CCS within it. First, actors acknowledge in principle that fossil fuels (and specifically coal) will continue to be important for some decades – but that coal with CCS is only a temporary solution. The exact amount and time span of coal use is, of course, much debated (the latter ranging from 30 to 100 years), as is the nature of the future energy system. Environmental NGOs tend to adopt a wider time horizon, discussing energy futures up to the year 2050–2100. Industry, coal organisations and BMWI (with few exceptions) prefer to restrict their goals and visions to a shorter term, pointing out that every statement concerning time beyond about 2030 would be highly speculative. If conceived at all, the future system is mostly said to be based on supply- and demand-side efficiency, decentral renewable energies and combined heat and power generation. Some actors also expect fuel cells, large (off-shore) wind power, hydrogen, large-scale imported renewables and/or nuclear fusion.

Secondly, actors also agree that CCS is no ‘magic bullet’ that will solve the climate issue without further changes in the energy system. Coal-based generation with CCS will be combined with gas-based generation and renewable energies. However, opinions differ wildly as to what the contribution of each of these options may be and to what extent they compete. Actors from coal industry tend to view gas as their main competitor. They see renewable energies as a complement but not a danger, since they do not expect significant base load capacity covered by renewables in the nearer future. For the same reason, electricity industry and the BMWI argue that coal with CCS might ‘fill the gap’ left by renewables.

Environmentalists and renewable energy lobbyists are ambivalent on the matter. On one hand, they are confident that cost reductions in renewable energies will make them competitive with coal and CCS. On the other hand, they fear that CCS might deduct funds from R&D on renewables, and that it could be an excuse for investment in large centralised power plants that cement supply structures unconducive to energy saving, decentralised renewable energies and CHP.

3.2.3 Problems and risks

The energy penalty is the one pressing issue perceived by all actors. It affects resource availability, drives up prices and increases the environmental burden of resource extraction. Also, actors agree that the technical feasibility of storage needs to be proven. Besides, environmentalists point to the issues of storage safety, long-term CO_2 mitigation and possible impacts on ecosystems, while electricity and power plant industry are concerned about cost and public acceptance.

3.3.3 Policy framework

All actors underline the necessity of a stable, long-term energy policy in order to provide security of investment. Electricity and plant industry does not reject climate policy outright, but rather demands climate protection goals to be predictable and internationally harmonised in order to prevent market distortion. A predictable and high CO_2 price is often cited as necessary for making CCS competitive with conventional fossil power plants. On the other hand, a high CO_2 price tends to favour gas and renewable energies over coal, which worries coal industry. These issues point to the relevance of future international climate policy and the development of the EU emissions trading system for the future of CCS.

Furthermore, CCS needs a simple and conducive framework with respect to licensing procedures, environmental and safety standards, regulation of international cooperation and liability rules in case of accidents. It seems likely that industry accepts rather ambitious safety standards because they are concerned about public acceptance. Many actors point to the necessity of regulating these issues, but very few detailed concepts have been worked out so far. We expect that, as the devil is in the details, concrete regulation of those issues will be a major source of conflict.

With respect to funding, there is little consensus emerging. All interview partners view massive R&D funding for a broad array of energy and climate technologies as necessary. Apart from that, however, there is little consensus – debate starting with the question of what a ‘broad array’ exactly means, to what degree it should include CCS and which options should be privileged. Coal mining industry and electricity suppliers call for massive R&D funding in order to cushion risks and uncertainties. By contrast, environmentalists, Green party members and renewables proponents claim that carbon *capture* research should be financed by industry. Still, some acknowledge that *storage* research should be a public issue in order to ensure high safety standards. In any case, (as advisory bodies also agree), CCS programmes should neither crowd out research in renewable energies and energy efficiency nor be used as a rationale for delaying adoption of policies to achieve near-term reductions in carbon emissions. Scientists, the Government and Social Democratic Party members point to the necessity of a calculable long-term framework for R&D with clear targets and an evaluation. Research on storage is, in their opinion, particularly relevant.

3.3.4 CCS and future coal use

There is no consensus on whether CCS will improve the chances of coal use in a future energy system or not. Perceptions run across established actor coalitions, ranging from ‘it is rather a risk’ via ‘it has no influence at all’ to ‘it presents a huge chance’. One reason for the differences is the differing perception of climate issues and of their relevance in public opinion. If climate issues are acknowledged and/or seen as a relevant topic in public opinion, actors feel that CCS might be beneficial for future coal use: it promises to reconcile coal use and climate protection and thus improve acceptance for coal.

If, in contrast, actors focus on topics like security of supply and energy prices (and/or see energy policy and the public debate as dominated by these issues), they will expect coal to be necessary and accepted to a great extent anyway. In this case, CCS would provide no additional benefit. In short, what makes it difficult to judge the effect of CCS on the future of coal is the fact that it may increase acceptance on one hand, while it raises cost and lowers profitability on the other hand. It is hard to balance the two countervailing effects, especially in the face of uncertainty of cost development.

3.4 Changes in influence patterns?

Does the debate on CCS affect actor resources and linkages and thus change influence patterns of actors in coal policy? We contend that CCS creates ambivalences and uncertainties, which partly cause traditional coalitions to loosen. The many open questions make actors more receptive to arguments and information. Many feel that they are in need of such information and therefore try to build contacts and stimulate constructive dialogue. The ambivalent effect on coal (increasing legitimacy but also cost) creates differing opinions, which can cause ruptures within the industry-coal-electricity coalition. Another interest divergence is between electricity suppliers with high and low shares of coal.

The same is true, however, for environmentalists. Positions are already diversifying, and the debate has not yet reached the broad member base of environmental NGOs. Some actors expect that members may not share the reluctant interest with which CCS is met in expert circles, but may be much more opposed so that serious controversies could result.

Thus, CCS weakens traditional ties on all sides and also provides all sides with new channels of information. It is not yet clear who will profit from this situation. However, this may lead to more realistic and consensual policy options in the long run, as described in Section 4.

4 Discussion: CCS and the future of coal in Germany

Our paper assessed the setting of actors with regard to a future deployment of CCS in Germany. We looked at the interests, activities and general attitudes of actors involved in this upcoming debate. In the following, we will present our conclusions as to the expected future of coal and CCS and close with a summary of preconditions for a sustainable transition of the electricity system – be it with or without CCS.

4.1 The potential future of coal and CCS in Germany

It is likely that *CCS will come*, most probably as an integrated process (no retrofit). Indicators are the increasing R&D activities – both nationally and internationally, by governments and by industry – and the fact that there are only few principally opposed actors. Activities to develop the necessary regulatory framework are already underway on an international level, although they are not so much recognised in the German debate. For example, the IPCC is currently issuing new guidelines for including CCS into national greenhouse gas inventories (Eggleston, 2006; IPCC, 2006). Also, in an October 2006 workshop, the International Energy Agency has done intensive work on legal aspects (IEA, 2006). As recommended by the Working Group on CCS under the Second European Climate Change Programme (ECCP II), the European Commission is planning to issue a Communication on CCS for the second half of 2007 and to develop draft legislation for the topics of risk, liability, legal barriers and incentives (Dimas, 2006b; Levefre, 2006; Working Group on CCS, 2006). However, even if CCS will come in Germany, it remains to be seen which share it will take on in the future electricity generation mix.

There is no single most important actor operating as the *driver* of CCS. Rather, we find an interdependence of a number of actors, each commanding different resources and benefiting from different linkages. We can discern, though, a more central set of actors (made up of electricity, power plant, and oil and gas industry, NGOs and ministries), from a more peripheral one (made up of parties, counselling bodies, trade unions and the mining industry).

The debate on CCS and the resulting movement in the actor constellation opens up space for the concept of fossil fuels – including coal – as transitional fuels. Environmentalists tend to acknowledge that fossils are necessary for a transition period. Coal proponents do not openly discuss the fact (but they do not deny it anymore either) that this transition period will end one day. CCS could thus help to reconcile fossil fuel use and climate protection during that transition period, provided that the numerous technical, economic, ecological and safety issues are resolved.

CCS may thus *prolong* the dominance of the current coal-to-electricity path to some 100 years, instead of about 40 years as maintained by environmentalists. As carbon separation is only viable for high-emission points, the current structure of centralised coal-fired power plants will be partly conserved. Not all investment is likely to flow into such plants, though – rather, a mix of central and decentralised options based on different fuels is likely to result. Such a trajectory seems reasonable as long as it is compatible with climate protection and other sustainability demands and as long as the transition period is used to develop alternatives to the fossil system that may ultimately result in a more 'renewable' future.

Timing is another important issue. With their 'three-step' concept, industry gives priority to the installation of current state-of-the-art plants, so that a number of conventional coal plants will have been installed by 2020 thus reducing the future CCS potential. Hence, coal has a future in Germany even without deployment of CCS. However, contrary to public perceptions, there is no 'window of opportunity' that strictly closes in 2020, the year often mentioned as the end of a period of necessary massive reinvestment in Germany. It is rather a continuous replacement process that still allows for a step-by-step implementation of CCS after 2020, followed by a slow but steady decommissioning of CCS plants towards the depletion of CO_2 storage capacities.

Aside from this, CCS is relevant not only for Germany. In fact, emerging economies like China and India (and other developing countries) have even more potential as addressees for the deployment of CCS (Watson, 2005; Unruh, 2006). Stern (2006, p.368) also points out that

> "… CCS is a technology expected to deliver a significant portion of the emission reductions. The forecast growth in emissions from coal, especially in China and India, means CCS technology has particular importance. Failure to develop viable CCS technology, while traditional fossil fuel generation is deployed across the globe, risks locking-in a high emissions trajectory."

For Germany, this opens up new perspectives for power plant industry – a new export market can be developed. To this end, technology development and implementation in Germany is an important step. However, whether CCS will take off in emerging economies ultimately depends on the climate regime.

4.2 Conculsion for a future deployment of CCS

In this last section, we draw some conclusions for the future development of CCS in the context of the total electricity system. We base them both on the potential role of CCS as a bridging technology and on the assessment of political actors' acceptance.

CCS should not be considered a magic bullet but as one option within a broad portfolio of climate protection measures, competing for their implementation. Such a broad portfolio allows to choose those options with lowest CO_2 mitigation cost. CCS can assume a specific role within that portfolio as a bridging technology during a transition from a carbon-based towards a carbon-free electricity system. Although there is widespread consensus on this idea, none of the actors portrayed here has developed scenarios for such transition so far. And none of them has an incentive to do so as long as they do not expect a stringent climate policy framework to enter into force. For environmentalists, doing so would mean to explicitly accept a prolongation of the carbon period (or even a carbon lock-in), which they are reluctant to do. Counselling bodies and the scientific community could be appropriate actors to solve this task, but have not yet dealt with the issue in detail.

Therefore, a clear and reliable policy framework needs to be in place to develop the portfolio of technologies and allow for a transition towards a low-carbon or even carbon-free future. Such a framework consists of four core elements.

First and foremost, power generation cost must reflect environmental cost. For this, clear and stringent climate targets are needed so that CO_2 has a price and CO_2 emissions become a relevant cost factor in electricity generation. This stimulates the development of efficiency and renewable technologies, and also of CCS. All actors accept or support long-term climate goals and policies, as long as they are stable, predictable and internationally harmonised. Policymakers should hence build on such consensus and offer a reliable framework.

Secondly, a pre-condition for CCS is a well-developed regulatory and institutional system in order to ensure a secure operation and monitoring of storage sites, to prevent leakage and to regulate liability issues. Secure operation needs to be made a pre-condition for CCS implementation.

Thirdly, public funding for CCS is needed to explore its potential. Here, policymakers can build on the consensus that a broad array of energy sources should be supported, and CCS should not crowd out research on renewable energies or energy efficiency. A sensible decision would be to focus public involvement on basic research and on the issues of public interest, like storage safety, while leaving commercial development of capture technologies as a task for industry R&D. An appropriate funding policy must also ensure the development of technologies that are not yet economic today, but may be needed in the future to combat climate change or replace scarce and environmentally problematic fossil fuels.

Finally, as public acceptance is an important aspect of a future deployment of CCS, any strategy to implement CCS needs active and open public outreach activities, combined with a well-developed regulatory framework.

To summarise, CCS is an incremental innovation that has a certain potential to smoothen a transition towards a less carbon-intensive energy future – provided that the related uncertainties are resolved, in particular with respect to leakage and liability. The actor constellation in Germany currently opens up such possible trajectories for using CCS as one bridging technology among others towards a more sustainable electricity system.

This paper could only touch upon a number of issues that deserve to be treated in more detail in future research. In particular, likely investment decisions up to 2020 and their dependence on climate and energy policy are the major issues to be investigated in more depth. A deeper analysis of actor constellations might shed more light on the question of who actually profits from the CCS debate and who is likely to gain more influence. The embedding of national trajectories in the international environment also deserves further attention. Ultimately, a scenario analysis for the transition of the electricity system towards a renewable energy future, which includes CCS and CCS combined with biomass as a fuel (net sink) and gives special attention to the issue of the appropriate timing of investment, is required.

Acknowledgements

The authors would like to thank Martin Cames, Martin Pehnt, Katja Schumacher, Günter Borm, Georg Erdmann, Ludwig Stroink, Friedrich Seefeldt, Gunnar Theißen, two anonymous reviewers and the participants of the BIEE 2005 Conference, Oxford, for their support and valuable comments on earlier versions. The paper reports on a case study within the research programme on 'Transformation and Innovation in Power Systems' (www.tips-project.de). We gratefully acknowledge the funding of our research by the German Ministry for Education and Research (BMBF) within its socio-ecological research framework (SÖF).

References

All internet resources last accessed on December 13, 2006.

BMWI (2005) Energy. Innovation and New Energy Technologies. The 5th Energy Research Programme of the Federal Government. July 2005, Available at: http://www.bmwi.de/English/Navigation/Service/publications,did=74976,render=renderPrint.html

BMWI (undated) Die COORETEC (Kohlendioxid-Reduktions-Technologien) Initiative. Available at: http://www.bmwi.de/BMWi/Navigation/root,did=28568.html

BMWI (2006) Energiedaten. August 2006. Available at: http://www.bmwi.de/BMWi/Navigation/Energie/Energiestatistiken/energiedaten.html

Coninck, H.C.de, Groenenbeg, H., Anderson, J., Curnow, P., Flach, T., Flagstad, O-A., Norton, C., Reiner, D. and Shackley, S. (2006) Acceptability of CO_2 capture and storage. A review of legal, regulatory, economic and social aspects of CO_2 capture and storage. ECN Report ECN-C–06-026. May.

COORETEC (2003) Forschungs– und Entwicklungskonzept für emissionsarme fossil befeuerte Kraftwerke. Bericht der COORETEC-Arbeitsgruppen. BMWA Dokumentation 527. Berlin, BMWA (Bundesministerium für Wirtschaft und Arbeit). Available at: http://www.fz-juelich.de/ptj/projekte/datapool/page/1329/doku527.pdf

Curry, T.E. (2004) *Public Awareness of Carbon Capture and Storage: A Survey of Attitudes toward Climate Change Mitigation*. M.I.T. Masters Thesis, June 2004. Available at: http://sequestration.mit.edu/bibliography/policy.html, last accessed 13 December 2006.

Curry, T.E., Reiner, D.M., de Figueiredo, M.A. and Herzog, H.J. (2005) *A Survey of Public Attitudes towards Energy and Environment in Great Britain*. Available at: http://sequestration.mit.edu/pdf/LFEE_2005-001_WP.pdf

Dimas, S. (2006a) *Answer of Commissioner Dimas on behalf of the European Commission to Question No. E-0075/06 by Member of European Parliament Daniel Caspary*, 10.06.2006, Document of the European Parliament, P6_RE(2006)0075.

Dimas, S. (2006b) *Speech at the General Assembly of the Technology Platform on Zero Emission Fossil Fuel Power Plants,* Brussels, 12 September 2006. Available at: http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/06/492

DIW (2005) *Climate Protection in the German Electricity Market: Opportunities for Coal Technologies through CO_2 Capture and Storage?* Weekly Report 16 of DIW Berlin. Available at: http://www.diw.de/english/produkte/publikationen/weeklyreport/index.html

Donner, S. and Lübbert, D. (2006) *Kohlendioxid-arme Kraftwerke. CO_2-Sequestrierung - Stand der Technik, ökonomische und ökologische Diskussion.* Info-Brief WF VIII G - 096/2005. Berlin: Deutscher Bundestag – Wissenschaftliche Dienste, 19.04.2006. Available at: http://www.bundestag.de/bic/analysen/2006/Kohlendioxid-arme_Kraftwerke.pdf

Eggleston, S. (2006) *Estimation of Emissions from CO2 Capture and Storage: the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Paper presented in the *UNFCCC Workshop on Carbon Dioxide Capture and Storage*, 20 May 2006, Bonn. Available at: http://unfccc.int/files/meetings/workshops/other_meetings/2006/application/pdf/ccs_20060723.pdf

EnBW (2005) Geschäftsbericht 2005. Available at: http://www.enbw.com/content/de/investoren/_media/_pdf/gb_2005.pdf

E.on (2005) Strategy & Key Figures 2005. Available at: http://www.eon.com/en/downloads/StrategieKennzahlen2005_en_Strategy_20050524.pdf

European Commission (2004) European CO_2 Capture and Storage Projects. European Commission, Directorate-General for Research, Directorate J – Energy, Unit J2 – Energy production and distribution systems. Available at: http://ec.europa.eu/research/energy/pdf/co2capt_en.pdf

European Commission (2006) A vision for zero emission fossil fuel power plants. Report of the European Technology Platform for Zero Emission Fossil Fuel Power Plants. DG Research, Brussels. Available at: http://ec.europa.eu/research/energy/pdf/zero_emission_ffpp_en.pdf

GESTCO (2004) Geological Storage of CO_2 from Combustion of Fossil Fuel. Summary Report. Available at: http://www.geus.dk/program-areas/energy/denmark/co2/GESTCO_summary_report_2ed.pdf

Grüne (2006) Für realistische Antworten auf den radikalen Klimawandel. Beschluss des Parteirats vom 6. November 2006. Available at: http://www.gruene.de/cms/files/dokbin/155/155478.beschluss_zum_klimawandel.pdf

Hawkins, D.G. (2001) Stick it Where? Public Attitudes toward Carbon Storage. Paper presented in the *1st National Conference on Carbon Sequestration*, 14–17 May, Washington, DC, USA. Available at: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/1c2.pdf

Hughes, T.P. (1983) *Networks of Power – Electrification in Western Society 1880–1930*. Baltimore and London: The Johns Hopkins University Press.

Idrissova, F. (2004) *Life Cycle Assessment of Selected Carbon Dioxide Capture, Transportation and Storage Options from Coal-fired Power Plants*. Diplomarbeit, Heidelberg.

IEA (International Energy Agency) (2004) *Prospects for CO_2 Capture and Storage*. Paris.

IEA (International Energy Agency) (2006) *2nd IEA Workshop on Legal Aspects of Storing CO_2*. Available at: http://www.iea.org/textbase/work/workshopdetail.asp?WS_ID=235

IPCC (2005) *Carbon Dioxide Capture and Storage.* IPCC Special Report. Available at: http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/SRCCS_WholeReport.pdf

IPCC (2006) *IPCC Guidelines on National Greenhouse Gas Emission Inventories*, forthcoming.

Jansen, D. (2003) *Einführung in die Netzwerkanalyse.* Opladen, Leske & Budrich.

Kharaka, Y., Cole, D.R., Hovorka, S.D., Gunter, W.D., Knauss, K.G. and Freifeld, B.M. (2006) 'Gas-water-rock interactions in Frio Formation following CO_2 injection: Implications for the storage of greenhouse gases in sedimentary basins', *Geology*, Vol. 34, pp.577–580.

Levefre, J. (2006) 'Towards an EU Policy Framework for CCS', Paper presented in the *UNFCCC Workshop on Carbon Dioxide Capture and Storage*, 20 May 2006, Bonn. Available at: http://unfccc.int/files/meetings/sb24/in-session/application/pdf/jl_ccs_presentation_20_may_bonn.pdf

Linßen, J., Markewitz, P., Martinsen, D. and Walbeck, M. (2006) *Zukünftige Energieversorgung unter den Randbedingungen einer großtechnischen CO_2-Abscheidung und Speicherung.* Abschlussbericht des Forschungsvorhabens FKZ 0326889, Bundesministerium für Wirtschaft und Technologie, April 2006.

Marsh, D. (1998) 'The development of the policy network approach', in D. Marsh (Ed.), *Comparing Policy Networks* (pp.3–17). Buckingham, Open University Press.

Matthes, F.C. and Ziesing, H-J. (2003) *Investitionsoffensive in der Energiewirtschaft – Herausforderungen und Handlungsoptionen. Kurzstudie für die Bundestagsfraktion Bündnis 90/Die Grünen*. Berlin. Available at: www.gruene-fraktion.de/cms/energie_klima/dokbin/35/35004.pdf

Nachhaltigkeitsrat (German Council for Sustainable Development) (2003) *The Perspectives for Coal in a Sustainable Energy Industry*. Berlin: Nachhaltigkeitsrat. Available at: http://www.nachhaltigkeitsrat.de/service/download/publikationen/broschueren/Broschuere_Kohleempfehlung.pdf

Pehnt, M. (2005) 'Environmental impacts of future energy systems', Paper presented in the *Risø International Energy Conference*, 26th May 2005. Roskilde. Available at: http://www.tips-project.de/download/mp_Future_Energy_Systems_Risoe_Paper.pdf

Perkins, R. (2003) Technological 'lock-in'. *Internet Encyclopaedia of Ecological Economics*, International Society for Ecological Economics. Available at: www.ecoeco.org/publica/encyc_entries/TechLkIn.doc

Peteves, S.D., Tzimas, E., Starr, F. and Soria, A. (2005) *Hypogen Pre-Feasibility Study*. Final Report, Prepared by ENEA, Italy; Fraunhofer ISI, Germany; Risø National Laboratory, Denmark. A study commissioned and guided by the European Commission, DG Joint Research Centre Institute for Energy and Institute for Prospective Technological Studies. January 2005. S.72–79. Available at: http://www.jrc.nl/downloads/file.php?id=9

Point Carbon (6.12.2006) UK treasurer dashes CCS hopes in green budget. Available at: http://www.pointcarbon.com/article19328-881.html?articleID=19328

Radgen, P., Cremer, C., Warkentin, S., Gerling, P., May, F. and Knopf, S. (2006) *Verfahren zur CO_2-Abscheidung und -Deponierung*. Fraunhofer Institut für Systemtechnik und Innovationsforschung (ISI) und Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). Forschungsbericht 203 41 110 des Umweltbundesamtes, Dessau, August.

RWE (2006) *RWE AG: Facts & Figures 2006: German Power Plant Portfolio 2005*. Available at: http://www1.rwecom.geber.at/factbook/en/servicepages/downloads/files/complete_rwecom_fact06.pdf

RWE Power (2006) *Leuchtturmprojekt der RWE-Klimastrategie: Das CO_2-freie Kraftwerk*. Presentation for press conference on 30 March 2006.

Schumacher, K. and Sands, R. (2006) 'Innovative energy technologies and climate policy in Germany', *Energy Policy*, Vol. 34, pp.3929–3941.

Shackley, S., McLachlan, C. and Gough, C. (2004) *The Public Perceptions of Carbon Capture and Storage*. Tyndall Centre Working Paper No. 44, Manchester, January 2004, Available at: http://www.tyndall.ac.uk/publications/working_papers/ working_papers.shtml#wp44

Stern, N. (2006) *Stern Review on the Economics of Climate Change*. Cambridge, UK, 30 October.

Stroink, L. (2006) Underground Storage of CO_2 in Germany – A new research programme as Part of the National R&D-Programme GEOTECHNOLOGIEN – *Greenhouse Issues*, No. 81, March 2006; IEA Greenhouse Gas R&D-Programme, Available at: http://www.ieagreen.org.uk/index.html

Umweltbundesamt (2003) *Anforderungen an die zukünftige Energieversorgung – Analyse des Bedarfs zukünftiger Kraftwerkskapazitäten und Strategie für eine nachhaltige Stromnutzung in Deutschland*. Berlin, Umweltbundesamt. Available at: http://www.umweltbundesamt.org/fpdf-l/2374.pdf

Umweltbundesamt (2006) *Technische Abscheidung und Speicherung von CO_2 – nur eine Übergangslösung*. Positionspapier des Umweltbundesamtes zu möglichen Auswirkungen, Potenzialen und Anforderungen. Climate Change Nr. 04/2006, Dessau, August.

Unruh, G.C. (2000) 'Understanding carbon lock-in', *Energy Policy*, Vol. 28, pp.817–830.

Unruh, G.C. and Carrillo-Hermosilla, J. (2006) 'Globalizing carbon lock-in', *Energy Policy*, Vol. 34, pp.1185–1197.

Vattenfall (2004) *Mining & Generation. Energie aus dem Nordosten. Daten und Fakten 2004*. Available at: http://www.vattenfall.de/www/vf/vf_de/Gemeinsame_Inhalte/DOCUMENT/154192vatt/Bergbau_und_Kraftwerke/P0283363.pdf

Watson, J. (2005) 'Advanced cleaner coal technologies for power generation: can they deliver?', Paper presented in the *2005 BIEE Academic Conference: European Energy – Synergies and Conflicts*, Oxford, 22–23 September.

WBGU (German Advisory Council on Global Change) (2003) *World in Transition: Towards Sustainable Energy Systems*. London: Earthscan.

WI (Wuppertal Institut für Klima, Umwelt, Energie), DLR (Deutsches Zentrum für Luft- und Raumfahrt), ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung), PIK (Potsdam Institut für Klimafolgenforschung) (2004a) *Ökologische Einordnung und strukturell ökonomischer Vergleich regenerativer Energietechnologien mit anderen Optionen zum Klimaschutz, speziell der Rückhaltung und Speicherung von Kohlendioxid bei der Nutzung fossiler Primärenergien.* First Interim Report. Wuppertal, Stuttgart, Potsdam, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. Available at: http://www.erneuerbare-energien.de/inhalt/20049/

WI (Wuppertal Institut für Klima, Umwelt, Energie), DLR (Deutsches Zentrum für Luft- und Raumfahrt), ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung), PIK (Potsdam Institut für Klimafolgenforschung) (2004b) RECCS. *Strukturell-ökonomisch-ökologischer Vergleich regenerativer Energietechnologien (RE) mit Carbon Capture and Storage (CCS)*. First Interim Report. Wuppertal. Available at: http://www.wupperinst.org/uploads/tx_wiprojekt/2112-statusrep1.pdf

Working Group on CCS (2006) *Report of Working Group 3: Carbon Capture and Geological Storage (CCS)*. The Second European Climate Change Programme. Final Report, 1 June 2006. Available at: http://forum.europa.eu.int/Public/irc/env/eccp_2/library?l=/geological_storage/final_reportdoc/_EN_1.0_&a=d

Notes

[1]A full list of sources is available in our respective Discussion Paper available at http://www.tips-project.de/download/TIPS_DP7_ccs_paper2005.pdf.

[2]However, the USA and Japan are considering ocean storage, and international legal barriers have been recently changing the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, so that CO_2 no longer counts as a pollutant (Point Carbon, 2006).

[3]At the time of the program launch: Federal Ministry of Economics and Labour (BMWA).

[4]See website www.geotechnologien.de.

[5]Jürgen Levefre, Policy coordinator on international climate change at DG Environment, in contrast, mentions 75 million EUR EU funding in FP 5 and 6 (Lefevre, 2006).

[6]See website at http://europa.eu.int/comm/research/energy/nn/nn_rt/nn_rt_co/article_2268_en.htm.

[7]See, for example, the recent RWE presentation, RWE Power, 2006.

[8]For the sake of clarity, it contains only organisations analysed in this report and only the most important linkages. Whenever actors are linked by different sorts of linkages, the figure shows only the strongest ones (common projects being assumed to be the strongest, followed by membership, resource flow and information flow).

Socio-technical implications of domestic microgeneration technologies in the UK electricity system

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Abstract: New technologies will play a crucial role in the transition to a sustainable energy system and a low or zero carbon economy more widely. Microgeneration technologies are one potential contributor to a sustainable energy system. From a Large Technical System (LTS) perspective, this paper explores the systemic challenges to increase the share of decentralised domestic microgeneration technologies in a system that has technically, institutionally and economically been characterised by a centralised approach to power provision. It argues that critical issues are linked to the institutional framework that inhibits the deployment of available technologies while technical issues are of lower importance at this stage. In the UK context, this paper analyses the extent to which existing policies and regulations address these issues, and more fundamental regulatory changes are outlined.

Keywords: large technical systems; microgeneration; UK.

Reference to this paper should be made as follows: Sauter, R. (2008) 'Socio-technical implications of domestic microgeneration technologies in the UK electricity system', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.204–219.

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1 Introduction

Increasing evidence on the influence of greenhouse gas emissions on dangerous climate change underlines the need for radical cuts in global carbon emissions over the next decades. European environment ministers concluded in 2005 that reduction targets of between 60 and 80% by 2050 compared with the Kyoto Protocol baseline are necessary

(Council of the European Union, 2005). Beyond the environmental dimension, a sustainable energy system involves economic and social aspects. A future energy system must use environmental and economic resources in its most efficient way possible and contribute to social equity.[1]

Domestic microgeneration technologies can be considered as one element to achieve a sustainable energy system. Micro renewables such as Photovoltaics (PV) and micro wind are zero emission technologies. Micro Combined Heat and Power Production (CHP) increase the overall efficiency as compared with central electricity generation in combination with a domestic condensing boiler.[2] The generation of energy at the point of use can increase the overall system efficiency where on average currently only a third of the primary energy input fed into the system is actually turned into useful energy for consumers. A considerable share of the generated electricity is lost in the transmission and distribution network.

The potential role of microgeneration technologies in a sustainable energy system in the UK is reflected by an increasing interest within industry and policy. Major UK energy suppliers have invested in these new technologies. E.ON Powergen has entered the initial stage of roll out of Stirling engine–based micro CHP units, British Gas (BG) have their own subsidiary, Microgen, developing a domestic CHP unit whose market launch is expected in early 2008. BG also concluded an exclusive agreement with the micro wind developer, Windsave. Scottish and Southern Energy have invested in the major UK PV manufacturer Solar Century and in the micro wind turbine manufacturer Renewable Devices.

The UK government published its Microgeneration Strategy (DTI, 2006b) in March 2006, which sets out plans to increase the use of microgeneration technologies in the UK. To date deployment in the UK has however been slow with only around 82,000 microgeneration technologies installed – out of which more than 78,000 are solar thermal heating systems (DTI, 2006b, p.14) – contributing virtually nothing to the national energy demand. However, the Energy Saving Trust has projected that microgeneration could supply 30–40% of UK electricity demand and reduce household carbon emissions by around 15% by 2050 (Energy Saving Trust, 2005b). Other factors such as the increase of an average UK household's electricity bill by 37% between January 2003 and March 2006 (Energywatch, 2006) also contributes to the increasing interest from homeowners in microgeneration as a way to reduce domestic electricity bills.

An increased share of microgeneration will challenge the existing electricity system not only in terms of the technical infrastructure (e.g. generation technology, networks) but also in terms of the institutional framework and the role of individual consumers. Individuals' involvement may go well beyond the mere hostage of units in their home: consumers may invest in their own electricity supply technologies and potentially change their pattern and level of electricity consumption (Dobbyn and Thomas, 2005). An increased deployment of microgeneration will interact and depend on a number of socio-technical factors.

The analysis in this paper draws on the Large Technical System (LTS) approach as initially developed by Thomas Hughes (1983). Applied to the UK electricity system, it discusses socio-technical implications and identifies policy and regulatory changes that may enhance the deployment of domestic microgeneration technologies considered as one potential contribution to a sustainable electricity system.[3] Due to the complexity and the set of issues involved, it is only possible to focus on a few critical issues within the scope of this paper.

While Sauter and Watson (2007a) were interested in an assessment of the disruptiveness of an increased share of microgeneration to the electricity LTS, this paper aims to identify critical issues within an existing electricity LTS with respect to an increase of domestic microgeneration using the UK as a case study. Central research questions of this paper are: What are the socio-technical implications of an increased share of domestic microgeneration technologies in the context of the UK electricity system? How can policy and regulatory changes increase the deployment of microgeneration in the UK? The analysis used two methodological approaches. First, 20 semi-structured interviews with relevant actors from policy, industry and lobbying organisations were conducted. The interviews covered five major areas: technology, economics, strategy, barriers and policy/regulation related to domestic microgeneration. Second, documents were consulted to gather further information relevant for the analysis.

The paper is structured as follows. Section 2 presents the LTS framework as analytical tool for the analysis. Section 3 identifies the critical issues in the transition to a sustainable electricity system in the UK. Section 4 discusses to what extent these critical issues have already been addressed in the UK and to what extent further changes could enhance the deployment of microgeneration technologies in the UK. Section 5 draws some conclusions.

2 Changes in existing electricity systems and domestic microgeneration

The majority of existing electricity systems is based on a central structure of electricity provision characterised by central power plants that provide electricity through the electricity transmission and distribution network to business or private customers. Institutions, such as early state bureaucracies (Mayntz, 1993), and more recent regulations, such as wholesale markets (Milborrow, 2001), have mainly been built around incumbent electricity generation technologies. Also new technologies have been mainly designed to fit into the existing 'Techno-Institutional Complex (TIC)' (Unruh, 2000). This 'entrenchment' of socio-technical system makes it difficult to keep large systems such as the electricity system under social control (Collingridge, 1992) and to introduce deliberate change.

Different theoretical approaches have been suggested to analyse system change. Strategic niche management (Kemp, Schot and Hoogma, 1998) focused on the niches to initiate regime shifts towards sustainability. Multi-level perspective (e.g. Geels, 2002) looked at the interaction of three levels – niche, regime and landscape – in order to understand how new technologies have been introduced in existing systems. This paper uses the LTS framework as theoretical approach. This section develops this framework as an analytical tool for the analysis of domestic microgeneration.

The LTS framework developed by Hughes (1983) from a historical comparative perspective on the evolution of different power systems was subsequently used and further developed in the analysis of various LTS, such as air traffic control, electricity supply industries and rail networks, and has proven as a robust framework to identify main system features. Three distinct features of an LTS can be distinguished (Geyer and Davies, 2000):

- A set of components that can be both technical (e.g. power stations, transmissions lines) and non-technical (e.g. consumers, distribution companies, environmental laws).
- A set of horizontal and vertical interconnections (which can also be both technical and non-technical) between the components; this means that changes in one component often lead to changes in others.
- A control component that sets out the way in which the economic and wider social performance of the system is regulated. Control is exercised by management and economic systems (e.g. wholesale power markets), technical systems (e.g. control technologies) and regulatory systems (e.g. through regulators).

While Hughes' interest was mainly on the invention and development of such systems, later studies were more interested in the question how change can be fostered in existing systems (Summerton, 1994a) and consequently on the governance of such systems (Coutard, 1999a). Hughes developed the concept of 'reverse salients' to capture the change in an existing LTS. These 'reverse salients' can however only occur if the system follows specific system goals. These goals were in the electricity system traditionally – according to Hughes – economic efficiency and security of supply. If individual system components do not comply anymore with the system goals, they constitute 'reverse salients'. System builders or managers need to find corrections for the failing components. Since all the system components are linked to each other, the change of one component is likely to cause changes with other system components or even create a whole new system.

The transition to a sustainable electricity system adds the system goal of low carbon emissions to the existing system objectives. As a consequence, carbon-emitting generation technologies become 'reverse salients' as they do not comply with all the system goals anymore. This process has also been described as 'undoing of closure' and as the pre-condition to 'reconfigure' an existing system (Summerton, 1994b). The introduction or increase of domestic microgeneration (as new technical component) is one possible way to correct reverse salients as long as it can prove its ability to contribute to *all* system goals. Due to the interconnected nature of the system, this new component is likely to lead to changes in other components. Thus, microgeneration is at the same time the cause for change and the result of ongoing changes.

Many historical studies on the electricity system such as Hughes' analysis were mainly interested in the supply side. Domestic microgeneration requires, however, an integrated view of the supply and demand side. While the role of society has been widely acknowledged in the construction process of an LTS, the role of individual consumers has been widely neglected (Summerton, 1994b; Coutard, 1999b; Joerges, 1999). One of the few exceptions is Nye (1998), who described the influence of consumers with their preferences and lifestyles on the construction and change of the electricity LTS in the USA. The role of the individual in the electricity system might change further with the introduction of microgeneration technologies. It may create a new public involvement in the provision of electricity captured in the term 'co-provision' (van Vliet, 2004). Energy supply technologies are not planned centrally anymore, but may be installed in millions of homes. As a consequence, the distinction between supply and demand dilutes.

The extent to which a new role for consumers and society as a whole will materialise will depend on the way microgeneration technologies will be deployed. Watson (2004) has initially suggested three different deployment models for microgeneration technologies, which were then further developed (Sauter and Watson, 2007b): ‘Plug and Play’, ‘Company Driven’ and ‘Community Microgrid’. Their distinct feature refers mainly to the degree of consumer involvement in terms of financing, operation and maintenance as well as behavioural changes. The three models aim to represent three rather ‘extreme’ cases, whereas many variations of these models are possible.

Under ‘Plug and Play’ the homeowner purchases, owns and runs the microgeneration unit, whereas under a ‘Company Driven’ approach an energy company offers a microgeneration unit to the customer including a financial and servicing package. In the longer term, an energy company might use microgeneration units as part of the generation supply portfolio. Alternatively, under ‘Community Microgrid’ microgeneration units could be used at the local level in the framework of a private community network (Jones, 2005). Each deployment model requires different technical changes. Company investment with remote control would require meter technologies with remote control including appropriate communication technologies.

Company-driven approaches might be particularly important at this early market stage due to the barriers to consumer investments (Sauter and Watson, 2007b). These are affected by a range of other factors including risks, imperfect information, bounded rationality and a lack of access to capital (Chesshire, 2003; Sorrell, 2004). In the case of microgeneration, risks associated with future energy prices and the reliability of new technologies are particularly important. Imperfect information may result from the lack of reliable sources as well as insufficient understanding of energy efficiency measures. Constraints in time, attention and the ability to process information lead consumers to make decisions under ‘bounded rationality’. Individuals rarely behave as rational economic agents and do not consider future savings or revenues fully (Oxera, 2005).

While the way and the extent to which individual components of the electricity LTS are affected by an increased share of microgeneration will depend on the deployment model; critical issues for regulatory and policy changes remain similar. It is regarded as crucial to create a technical and institutional framework that allows for all possible deployment models to be implemented. For the subsequent analytical application of the LTS framework, Table 1 summarises individual components of the electricity LTS and the different actors involved.

The technical components comprise the design of the generation technologies, the electricity network and metering technologies used. Non-technical components are include the ownership of the network and generation capacities, the supply chain (installers’ network), consumer–supplier relationship and skills. Finally, control components refer to the overall regulatory setting including load management, the wholesale market and financing.

Table 1 LTS components and actors involved

The electricity system as LTS	*Actors involved*
Technical components	
Design/embodiment of electricity generation technology	Manufacturers, installers, consumers
Electricity network	Transmission network operator, Distribution Network Operator (DNO), suppliers, regulator, telecommunication industry
Metering	Suppliers, DNO, regulator
Non-technical components	
Network ownership	Network operators, suppliers
Generation ownership	Generators, suppliers, consumers
Supply chain / installers' network	Product supplier, installers
Consumer-supplier relationship	Consumers, suppliers, regulator
Skills (labour, managerial/technical)	Manufacturers, installers, architects
Control components	
Regulatory setting	Regulation authority, all market participants, government

Source: Adapted from Sauter and Watson (2007a).

3 Critical socio-technical and institutional issues for microgeneration in the UK

This section discusses the technical, non-technical and control LTS components in the context of domestic microgeneration technologies in the UK. For each component, it will briefly outline the current situation in the UK and how microgeneration relates to them considering different deployment models where relevant. This allows identifying critical issues for system change under the assumption that microgeneration might play an increasing role in the future UK energy supply system. The discussion focuses on some critical issues and emphasises the interconnections between system components.

Technical components: generation technologies, electricity network and meters.

The current UK electricity supply is dominated by large power plants. The installed capacity of around 77 GW operational at the end of May 2005 is dominated (83%) by plants with a capacity of over 500 MW (DTI, 2005a). If the potential of microgeneration technologies was fully exploited, they could cover up to 40% of electricity demand in the UK (Energy Saving Trust, 2005a); this would entail a considerable change of technical system components. As regards the future contribution of the different microgeneration technologies, the EST study predicts that Stirling-based micro CHP technology will have the highest share by 2030 with a contribution of up to 5% to UK electricity demand of 380 TWh. Micro wind could also contribute up to 1%, while PV will play a rather marginal role (Energy Saving Trust, 2005b). The share of individual technologies will depend on their potential for further improvements in their technical and economic performance.

While PV is an established and proven technology its installation costs are still high; micro wind and micro CHP are new technologies with very few field trial data available. Although the first units of micro wind and micro CHP have been installed in the UK, their overall long-term performance has still to be proven. Modelling results for micro wind suggest that the performance in urban and suburban areas will be rather poor (Watson et al., 2006). With some delays, the first units of Stirling engine–based micro CHP units are being commercialised in the UK.

The dominance of central power plants in any electricity system affects other system components. The electricity network was built to supply the electricity generated in central power plants to decentralised demand in individual homes and thus benefiting from the economies of scale based on the transmission of electricity from units with high voltage to lower ones. While currently the low number of units installed in the UK does not raise major technical problems for existing networks, increased shares of microgeneration connected to the grid may cause problems such as voltage unbalance problems. The overall physical impact of microgeneration will, however, be incremental and will therefore allow system operators to adopt their grids to these new challenges (Mott MacDonald, 2004). The upgrade of networks plays a crucial role in the transition to a decentralised electricity system and is less a technical issue but a question of network regulation (e.g. Bauknecht et al., 2006). The need for major investments in the UK network over the next years opens a window of opportunity to consider technical requirements for an increased share of microgeneration technologies.

Most of the 25 million UK homes have a single-phase import meter for billing purposes. Meters are critical for possible support policies (metering of the electricity generated and/or exported) and potential behavioural changes in electricity consumption (feedback on consumption pattern and levels potentially on a real-time basis). Although meters are a technical component of the electricity LTS, their implications are much broader.

Non-technical components: network ownership, generation ownership, consumer–supplier relationship, supply chain and skills.

In Great Britain, there are currently one transmission grid company and 14 Distribution Network Operators (DNOs) responsible for the operation and maintenance of the grid. Major issue for microgenerators is the fair access to the grid.

The number of electricity generators in the UK increased since 1990 from 6 to 32 in 2004, with seven of these companies producing at least 5% of total electricity generation each (DTI, 2005b, p.77). Most of these generation companies are owned by energy suppliers. If microgeneration fits into this ownership, structure will depend on the deployment model chosen. While supply companies could expand their generation capacity by installing and owning microgeneration units equipped with communication and control technologies, homeowners purchasing and running microgeneration units could also become a major player on the supply side of the energy system. As a consequence, the relationship between suppliers and consumers could change quite radically. While under ‘Plug and Play’ (see Section 2), one likely motivation is to increase the independence from the supplier; ‘Company Driven’ approaches could strengthen this relationship if the microgeneration contract is concluded for a longer period of time to allow the company to recover the investment. However, the ‘Plug and

Play' deployment model could also consolidate a supplier's relationship to its customers. If the payment of an export reward is not obligatory but offered on a voluntary basis from the energy supplier, a reward system could strengthen the customer–supplier relationship.[4] Incumbent energy suppliers will lose customers if microgeneration will be part of the new local grid company that manages a 'Community Microgrid'. In this case, consumers could get involved in the electricity system as stakeholders in their local supply company. Energy companies will have to cope with more independent consumers or offer new microgeneration packages to their customers. Alternatively, new energy service companies could challenge incumbent energy suppliers with energy service contracts for domestic microgeneration.

For 'Plug and Play', models to materialise installer networks for domestic energy generation technologies could be an essential accelerator. They will play a central role in providing homeowners with the necessary access to information and understanding of the new technologies. By September 2006, only a total of 380 installers were accredited under the Low Carbon Buildings Programme (LCBP) (see below) in the UK – out of which only around 60 installers were accredited for the installation of PV and wind turbines for the whole UK (Energy Saving Trust, 2006). Micro CHP will, in most cases, be a distress purchase, i.e. micro CHP is most likely to be installed when the existing boiler breaks down. Consequently, the decision will be taken very quickly based on the local installer's advice. About 100,000 registered installers in the UK will have to integrate this new technology into their daily business (SBGI, 2003). The UK energy supply companies could use their established installer networks to market, install and service these technologies.

Alongside the development of a supply chain, skills must be available to deal with microgeneration technologies. New skills will have to evolve in different areas in order to cope with domestic microgeneration technologies. Boiler installers need to be able to deal with the electrical components of micro CHP units, in order to avoid additional costs for an electrical engineer to connect the unit to the grid. Furthermore, grid companies, data collectors and aggregators as well as energy companies themselves will have to upgrade their management and billing systems in order to allow for the inclusion of microgeneration output.

Control components: regulatory setting

Most relevant regulations for domestic microgeneration technologies in the UK concern the domestic electricity retail market, the electricity network, metering and fiscal rules. The domestic retail market is mainly regulated by the Supply Licence Condition (SLC). Main SLC feature is the 28-day rule, whose main objective has been to encourage competition in this market segment. This provision allows customers to switch their energy supplier every 28 days. Since full opening of the domestic retail market, over 50% of UK customers switched at least once. At the beginning of 2006 350,000 electricity and 300,000 gas customers switched their supplier every month (Ofgem, 2006b). While the 28-day rule is one barrier that prevents suppliers from offering microgeneration contracts which would have to run over a longer period to guarantee a sufficient return from the investment, high switching rates make suppliers to think about ways how to retain customers over a longer period of time. Microgeneration contracts could be one way to achieve this.

Metering regulations in the UK were mainly aimed to create competition in the metering market. This led to the unbundling of the provision of meters and related services (e.g. meter reading) from DNOs. This creates major barriers for the introduction of new meter technologies that are considered as important for the deployment of microgeneration as outlined earlier. The possibility to loose a customer after 28 days makes the investment in new metering assets unattractive, facing the risk of stranded assets.

Another important area of regulation is the wholesale market that is regulated under the British Electricity Trading and Transmission Arrangements (BETTA) introduced on 1 April 2005. Under BETTA market, participants have to submit forecasts of the production and demand an hour in advance. Unpredictability of power output reduces the value of the output at the wholesale market level. It favours traditional generation technologies and affects the value of less predictable energy sources such as wind energy negatively (Milborrow, 2001). While the use of profiles could reduce related problems, profiles tend to fail to reflect the real-time value of microgenerated output. Real-time pricing can, however, be particularly attractive for microgeneration technologies generating electricity at peak times such as micro CHP (morning and evening in the winter season). Profiles also fail to provide possible incentives for behavioural changes through time of day pricing schemes. The UK balancing and settlement system is therefore not sufficiently prepared for the inclusion of micro-generated electricity. Exports are only 'spilled' into the distribution network.

Fiscal rules are an other important control component as they are one relevant aspect of investment decisions. Existing fiscal regulations for new investments in the UK electricity system have been built around the centralised technical infrastructure where investments are largely driven by companies (Chesshire, 2003). As a result, there are huge fiscal inequalities between domestic investments in microgeneration technologies and companies' investments in central power plants. While companies can write off their investments, households cannot. Furthermore, businesses investing in certain energy efficiency measures have access to Enhanced Capital Allowances (ECA), which means that they can write off 100% of their investment against their taxable profits in the year of investment (Watson et al., 2006, p.15f). This division between households and businesses reflects the traditional supply–demand distinction within the electricity system.

This section discussed some critical issues for the take up of microgeneration technologies in the UK electricity LTS. While distinguishing analytically between three dimensions (technological, non-technological and control components), their interconnections and interdependences became evident. It showed how the regulatory setting – or control components – developed for technical and non-technical components in a centralised system inhibit the increase of microgeneration technologies: the 28-day rule is one factor that prevents incumbent companies to offer microgeneration contracts, which could create an important push for technological deployment and development; metering regulations lead to risks of stranded assets and deter companies from investing in new metering technologies considered as important enabling technology for the uptake of microgeneration, and fiscal rules disadvantage investment in microgeneration technologies.

4 Regulatory and policy changes for microgeneration

In this section, the existing support policies and regulatory changes in the UK are assessed in how they address critical issues identified in Section 3. In a second step it outlines strategies for regulatory changes that can drive changes in technical and non-technical components and thus accelerate the deployment of microgeneration in the UK.

4.1 Changes in the regulatory setting so far

Several support policies have been introduced in the UK so far to – implicitly or explicitly – increase the attractiveness of microgeneration. These were mainly the Renewables Obligation (RO), capital grants and the Energy Efficiency Commitment (EEC). The RO was introduced in April 2002, and obliges electricity suppliers in the UK to prove that a certain share of their supplied electricity is generated from renewable energy sources. The share increases annually from 3% in 2002–2003 to 15.4% in 2015–2016.[5]

LCBP grants are available for PV and micro wind. The overall budget of £6.5 million for grants for private individuals over 3 years is rather low. The mechanism of a rolling first-come-first-served basis is likely to lead to frustration with interested parties. Experiences with previous grant programmes have shown the risk of a stop-and-go for the UK market with investment risks for manufacturers (Hickman, 2006).

EEC II imposes a domestic energy efficiency target of 130 TWh shared by all UK energy suppliers and runs from 2005 to 2008. Suppliers are free to choose from a list of approved measures. Supplier costs associated with EEC implementation can be recovered from customers' energy bills. New in EEC II are 'Innovative Actions' that encourage suppliers to use new measures to achieve their target (Ofgem, 2005a). Micro CHP is included as innovative action, but without any measurable impact so far.

The tax regime was changed in favour of microgeneration. A reduced VAT of 5% for microgeneration technologies is applicable if the purchase does also include a service (e.g. the installation of the unit).

Network regulations include an obligation for DNOs to connect microgenerators to their grid. The new distribution price control review introduced in April 2005 included Registered Power Zones and the Innovation Funding Incentive. The rules for these initiatives have, however, been criticised for not being flexible enough for DNOs to invest substantively in R&D activity and may therefore miss its innovation objectives (Woodman, 2006).

Changes in local planning regulation with the Planning Policy Statement on Renewable Energy (PPS22) in 2004 allows local planning authorities to require a percentage of the energy to be used in new residential areas to be covered from on-site renewable energy developments and should encourage this. The London Borough of Merton took the lead by imposing a 10% carbon emission reduction target in all new non-residential developments by renewable energies. The Town and Country Planning Association estimates that if 250 of the larger local authorities adopt a similar policy to Merton, this will create a £750 million per year market for solar PV, solar thermal and micro-wind (ENDS Report, 2006).

These measures can, to a certain extent, support an increased deployment of microgeneration technologies, but overall they are not focused enough to kick-start the market as the numbers of installed units show. Changes in the control components are too incremental to cause sufficient changes in the technical and non-technical components. The current version of RO does not consider cost differences between the different technologies and entails high administrative burdens; the LCBP is generally underfunded, which will delay the proof of technical reliability of microgeneration technologies to consumers and other investors alike. EEC does not provide sufficient incentives for new and therefore more expensive technologies to be deployed, for example, in the form of energy service contracts. Reduced VAT for microgeneration is a very incremental start to correct unequal treatment of large-scale and small-scale investments in the electricity system.

4.2 Potential measures for system change

The challenge for policies and regulatory changes is to establish an institutional framework that provides enough incentives and allows for the components of decentralised nature to be installed. It needs to ensure favourable conditions for all possible deployment models for microgeneration technologies, and thus create a longer-term perspective for all potential market participants. Possible changes and their expected impacts are outlined in the following with respect to the 28-day rule, fiscal rules and the balancing and settlement system as well as metering regulation.

The removal of the 28-day rule from the Supplier Licence Condition as suggested by Ofgem (Ofgem, 2006c) would allow energy companies to offer new contracts linked to microgeneration technologies with the prospect to establish a long-term relationship with customers. In the context of very low margins in the UK energy retail business, supply companies are looking at new business opportunities. Microgeneration contracts would provide an opportunity to sell other home services. Such offers will, however, depend on changes in the fiscal regime. Under current regulations, capital investments under energy service contracts for domestic dwellings does not qualify for capital allowances.

Fiscal rules for investments in energy supply infrastructure need to overcome the traditional distinction between supply and demand side, where only business is considered as investor in new supply capacity. ‘Plug and Play’ investment models for microgeneration make this distinction obsolete. Access to similar tax breaks for individuals – as companies already have – would provide an attractive investment framework as has been shown elsewhere (Watson et al., 2006). Different ways to implement changes have been suggested (ibid.): Taxpayers could offset investment costs against their taxable income or existing ‘salary sacrifice’ schemes[6] could be extended to include domestic green investments such as microgeneration. Such schemes could be financed using funds from the Environmental Transformation Fund (DTI, 2006a, p.15) or the Non-Fossil Fuel Obligation (NFFO) fund.[7] Tax allowances for homeowners may be particularly interesting at an early stage of a market when it is more likely that high-income groups invest into new technologies (Fischer, 2006).

A ‘level playing field’ would also include rewards for microgenerators’ output exported to the public grid, which exists only on a voluntary basis in the UK (see earlier). This would further improve the economic attractiveness of domestic microgeneration technologies. The Climate Change and Sustainable Energy Act (CCSEA)[8] adopted in 2006 obliged energy suppliers to develop a scheme of export rewards for microgenerators within 12 months after its publication. Otherwise, the government can impose a scheme. Such a reward scheme could be based on fixed export payment per kWh (exported or generated) or based on actual market prices using real-time metering. This will also depend on the settlement system and the meter technologies available.

In the settlement system, flows are either included on the basis of profiles (average pattern and level of consumption or generation) or real-time data. The latter is currently only used for industrial consumers with around 100,000 half-hourly meters installed. In

2003, a regulatory modification (known as 'P81') enabled suppliers to include exported electricity from microgenerators in the settlement system without the obligation to install half-hourly metering in the settlement system. The transaction costs are, however, very high as compared to the value of the generated electricity (DGCG Technical Steering Group, 2004). While profiles provide predictability to microgenerators' output which is important under BETTA regulations (see above), profiles prevent generators from access to real-time pricing. P81 profiles are not very accurate which prevents suppliers to use them. Industry players actively pursue the establishment of new profiles or the improvement of existing P81 profiles, instead of the usage for half-hourly data. The underlying reason for this might, however, be not primarily related to the involved technology and its costs but the institutional setting. While for the costs related to the establishment and maintenance of profiles for the settlement system, a cost sharing mechanism between all BSC parties is in place; costs for meter upgrade, data collection and aggregation would have to be covered by the individual supplier. The use of half-hourly metering instead of profiles depends on the upgrade of data collection and aggregation systems. Suppliers and DNOs suggest that their systems are not able to cope with half-hourly data from thousands of microgeneration units, and upgrading is not attractive due to high transaction costs. Furthermore, data collectors' and aggregators' activities are not regulated and controlled by Ofgem. Their claims for very high costs related to half-hourly metering are therefore difficult to verify or falsify. In any case, the settlement system should fully recognise the embedded benefits of microgenerators in terms of reduced network usage and the reduction in peak load.

Smart meters would help to solve issues like metering and data gathering from microgenerators. The role of smart meters would, however, require a change in the unbundled UK meter market. In its recent publication on metering innovation in the domestic sector, Ofgem (2006a) acknowledged that under the current framework major investments in new metering technology is rather unlikely. Although the consultation document discussed the option of re-bundling meter ownership and services to DNOs and imposing an obligation to install new meters, it underlined the reluctance to this step 'backwards' in order to encourage the introduction of innovative domestic meters. Thus, the regulatory setting prevents the upgrade in a key technical component of the existing LTS for a transition towards a more sustainable electricity system with a higher share of microgeneration technologies.

5 Conclusion

This paper analysed the socio-technical implications of domestic microgeneration technologies using the UK electricity system as a case study. It applied an LTS framework to identify critical issues in the transition to a sustainable electricity system. It highlighted the potential supportive policy and regulatory measures for this change.

So far, changes in the UK electricity system and its components have been corrections without questioning the concept of centralised electricity provision due to their incremental nature. While the deployment model of microgeneration will influence the socio-technical implications caused and changes required, critical issues for general deployment of microgeneration were identified. Measures to address these issues have to be based on an integrated approach including both supply and demand. The analysis of different system components has shown that technical issues are not the central barriers for change. The institutional framework built around the technical system components has to be adapted to a new form of electricity provision.

Under existing competitive regulation of the domestic energy retail market and metering market, necessary investments in new technical and non-technical components are unattractive facing the risk of stranded assets. Energy service contracts for domestic microgeneration need a long-term perspective. Instead of different players developing their own strategies and technologies for new meter technologies at increased costs, the regulator could coordinate players' action in this area. Not only would this enable the settlement of microgenerators' output at a real-time basis and potentially give access to 'fair' prices but would also provide more information and feedback to customers in order to enhance behavioural changes. As a consequence, investments in microgeneration technologies and new approaches to energy efficiency and energy services more broadly could be triggered.

A level playing field between all potential market participants and generation technologies by changing the tax regime and establishing a reward scheme for electricity exports could contribute to an increased deployment of microgeneration technologies in the UK. New regulatory standards, such as a minimum share of microgenerated energy provision in new developments or the installation of micro CHP in suitable homes, could further support this new market. Suitability should, however, not only refer to technical issues (e.g. sufficient heat demand in the case of CHP) but also refer to social aspects (e.g. fuel poverty in the UK). Incumbent suppliers may then integrate microgeneration into their customer packages, and households purchase their own microgeneration unit. This will allow the technologies to prove their reliability, reduce costs and may create further positive knock-on effects in other system components.

Whilst the LTS framework has proven as helpful analytical tool to identify critical issues for the uptake of microgeneration technologies in the UK with respect to different system components, the empirical analysis has also highlighted limits of this theoretical approach. The analysis suggests that more emphasis should be placed on the processes that enable or inhibit change of certain system components. The importance of linkages and interdependencies between the different system components indicate that more aggregate categories might be helpful for a better understanding of the issues involved. Future research in this area might address these challenges by analysing how changes in different system components relate to each other in terms of the provision of certain system functions that are required for the development of new technological systems (Jacobsson and Bergek, 2004).

Acknowledgments

This research was made possible by a grant from the UK Economic and Social Research Council under its Sustainable Technologies Programme (grant ref. RES-338-25-0003). The author would like to thank Jim Watson and two anonymous referees for their helpful comments. The usual disclaimers apply.

References

Bauknecht, D., Späth, P., Leprich, U. and Rohracher, H. (2006) 'Transformation der Stromwirtschaft: Die Rolle der Netze und ihrer Regulierung', in M. Bechberger and D. Reiche (Eds), *Ökologische Transformation der Energiewirtschaft* (pp.257–275). Berlin: Erich Schmidt.

Chesshire, J. (2003) 'Energy efficiency projects and policies for step changes in the energy system: developing an agenda for social science research', ESRC Seminar, Policy Studies Institute, March.

Collingridge, D. (1992) *The Management of Scale: Big Organizations, Big Decisions, Big Mistakes*. London: Routledge.

Council of the European Union (2005) Press Release, 2647th Council Meeting Environment, Brussels, 10 March 2005.

Coutard, O. (Ed.) (1999a) *The Governance of Large Technical Systems*. London: Routledge.

Coutard, O. (1999b) 'Introduction: the evolving forms of governance of large technical systems', in O. Coutard (Ed.) *The Governance of Large Technical Systems* (pp.1–16). London: Routledge.

DGCG Technical Steering Group (2004) Reward Mechanisms for Micro-Generation. DGCG.

Dobbyn, J. and Thomas, G. (2005) 'Seeing the light: the impact of micro-generation on our use of energy', *Sustainable Consumption Roundtable*, London.

DTI (2005a) Energy statistics: electricity – plant capacity UK (last updated 28 July 2005). Available at: http://www.dti.gov.uk/energy/inform/energy_stats/electricity/index.shtml

DTI (2005b) UK Energy Sector Indicators 2005.

DTI (2006a) 'The energy challenge, *Energy Review*, DTI, London.

DTI (2006b) *Our Energy Challenge, Power from the People*. London: DTI.

ENDS Report (2006) 'Tories secure renewables planning review', *ENDS Report*, Vol. 373, p.7.

Energy Saving Trust (2005a) 'Potential for microgeneration, study and analysis', Available at: http://www.dti.gov.uk/energy/consultations/pdfs/microgeneration-est-report.pdf

Energy Saving Trust (2005b) 'Potential for microgeneration. study and analysis', Energy Saving Trust.

Energy Saving Trust (2006) Personal e-mail communication, 28/10/2006.

Energywatch (2006) Personal communication – unpublished calculations.

Fischer, C. (2006) 'From consumers to operators: the role of micro CHP users', in M. Pehnt, M. Cames, C. Fischer, B. Praetorius, L. Schneider, K. Schumacher and J.P. Voß (Eds), *Microgeneration. Towards a Decentralized Energy Supply*. Heidelberg: Springer.

Geels, F.W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy*, Vol. 31, pp.1257–1274.

Geyer, A. and Davies, A. (2000) 'Managing project-system interfaces: case studies of railway projects in restructured UK and German markets', *Research Policy*, Vol. 29, pp.991–1013.

Hickman, M. (2006) 'Households lose incentives to install solar power', *The Independent*, 3/04/2006, p.2.

Hughes, T.P. (1983) *Networks of Power Electrification in Western Society, 1880–1930*. Baltimore: Johns Hopkins University Press.

Jacobsson, S. and Bergek, A. (2004) 'Transforming the energy sector: the evolution of technological systems in renewable energy technology', *Industrial and Corporate Change*, Vol. 13, pp.815–849.

Joerges, B. (1999) 'High variability discourse in the history and sociology of large technical systems', in O. Coutard (Ed.), *The Governance of Large Technical Systems* (pp.258–289). London: Routledge.

Jones, A. (2005) 'Local sustainable community energy', Paper presented in the *RPA Micro Renewables Conference*, London, 9 June 2005.

Kemp, R., Schot, J. and Hoogma, R. (1998) 'Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management', *Technology Analysis & Strategic Management*, Vol. 10, pp.175–195.

Mayntz, R. (1993) 'Große technische Systeme und ihre gesellschaftstheoretische Bedeutung', *Kölner Zeitschrift für Soziologie und Sozialpsychologie*, pp.97–108.

Milborrow, D.J. (2001) *PIU Working Paper on Penalties for Intermittent Sources of Energy*. Available at: http://www.strategy-unit.gov.uk/files/pdf/Milborrow.pdf

Mott MacDonald (2004) *System Integration of Additional Micro-generation*. London: DTI.

National Audit Office (2005) *Department of Trade and Industry, Renewable Energy*. The Stationary Office, London.

Nye, D.E. (1998) *Consuming Power: a Social History of American Energies*. London: MIT Press.

Ofgem (2005a) Energy Efficiency Commitment 2005–2008 Innovative Action (Decisions document, November 2005). Ofgem.

Ofgem (2005b) 'Social action strategy', Available at: http://www.ofgem.gov.uk/temp/ofgem/cache/cmsattach/11775_15505a.pdf

Ofgem (2006a) *Domestic Metering Innovation*. Ofgem.

Ofgem (2006b) *Domestic Retail Market Report – September 2005*. Ofgem, London.

Ofgem (2006c) Supply Licence Review – Initial Policy Proposals.

Oxera (2005) Policies for energy efficiency in the UK household sector. (unpublished report prepared for Defra for the CCPR).

Sauter, R. and Watson, J. (2007a) 'Micro-generation: a disruptive technology for the energy system?', in J. Murphy (Ed.), *Governing Technology for Sustainability*. London: Earthscan.

Sauter, R. and Watson, J. (2007b) 'Strategies for the deployment of microgeneration: implications for social acceptance', *Energy Policy*, Vol. 35, pp.2770–2779.

SBGI (2003) 'MicroCHP – delivering a low carbon future', SBGI, Available at: http://www.sbgi.org.uk/index.php?fuseaction=sbgi.viewFile&id=8010979

Sorrell, S. (2004) 'Understanding barriers to energy efficiency', in S. Sorrell, E. O'Malley, J. Schleich and S. Scott (Eds), *The Economics of Energy Efficiency* (pp.25–93). Cheltenham: Edward Elgar.

Summerton, J. (Ed.) (1994a) *Changing Large Technical Systems*. Boulder: Westview Press.

Summerton, J. (1994b) 'Introductory essay: the systems approach to technological change', in J. Summerton (Ed.), *Changing Large Technical Systems* (pp.1–21). Boulder: Westview Press.

The Carbon Trust (2005) The Carbon Trust's Small-Scale CHP field trial update. The Carbon Trust, Available at: http://www.thecarbontrust.co.uk/carbontrust/about/publications/181105_01.pdf, 22/11/2005.

Unruh, G.C. (2000) 'Understanding carbon lock-in', *Energy Policy*, Vol. 28, pp.817–830.

van Vliet, B. (2004) 'Shifting scales of infrastructure provision', in D. Southerton, H. Chappells and B. van Vliet (Eds), *Sustainable Consumption: the Implications of Changing Infrastructures of Provision* (pp.67–80). Cheltenham: Edward Elgar.

Watson, J. (2004) 'Co-Provision in sustainable energy systems: the case of micro-generation', *Energy Policy*, Vol. 32, pp.1981–1990.

Watson, J., Sauter, R., Bahaj, B., James, A., Myers, L. and Wing, R. (2006) *Unlocking the Power House: Policy and System Change for Domestic Micro-Generation in the UK*. Brighton: SPRU.

Woodman, B. (2006) 'Ofgem, distributed generation and innovation: recent initiatives', Paper presented in the *BIEE/UKERC Academic Conference*, Oxford, 20–21 September.

Notes

[1]This is, for example, relevant in the UK where "a household is defined as being in fuel poverty where it would need to spend more than 10 per cent of its income on energy to maintain a satisfactorily warm home" (Ofgem, 2005b). Although fuel-poor households in the UK fell from 5.5 million in 1996 to 2.25 million in 2002 due to improved incomes and falling energy costs, fuel poverty might rise again with recent energy price increases.

[2]More robust evidence is needed to prove the actual carbon reductions from micro CHP. Ambiguous interim results from a micro CHP field trial run by the UK Carbon Trust (The Carbon Trust, 2005) were strongly criticised by manufacturers.

[3]The focus of this paper on the electricity system does not imply that heat or transport are less relevant.

[4]For example, E.ON Powergen and Good Energy offer export or generation rewards to their customers only.

[5]The initial RO set a target only until 2010–2011 but was extended until 2015–2016 in April 2005.

[6]Under a 'salary sacrifice' scheme, the "employee gives up the right to receive part of the cash pay due under his or her contract of employment. Usually the sacrifice is made in return for the employer's agreement to provide the employee with some form of non-cash benefit" (HMRC, http://www.hmrc.gov.uk/specialist/salary_sacrifice.pdf#search=%22hmrc%20salary%20sacrifice %20scheme%22). The employee benefits from lower tax payments and NI contributions, the employer saves NI contributions.

[7]When the Renewables Obligation (RO) was introduced in 2001, already existing renewable energy sites built under the NFFO were included in the RO. The surplus benefits generated went into the NFFO fund administered by Ofgem. Over the period to 2010, this fund is expected to be between £550 million and £1 billion, while only £60 million are so far earmarked for the promotion of renewable energy (National Audit Office, 2005).

[8]http://www.opsi.gov.uk/ACTS/acts2006/ukpga_20060019_en.pdf

En'lightening' energy use: the co-evolution of household lighting practices

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Abstract: Compact Fluorescent Light Bulbs (CFLs) are a well-developed, readily available technology that could deliver substantial energy savings in the residential sector. Due to this, lighting is usually a preferred target for household energy-saving campaigns and policies. However, the energy used to light homes continues to rise. In order to explore the reasons behind this increase, this paper examines changing household lighting practices in the UK using recent in-depth interview data and drawing upon current sociological theories about the construction of consumption practices. The paper illustrates how lighting choices made by householders tend to co-evolve with the household lighting practices portrayed by the media. It concludes that policies seeking to promote energy-efficient lighting technologies would be well advised to enlist the support of lighting designers, manufacturers, advertisers and sales people involved in the presentation of household lighting practices in the media.

Keywords: energy consumption; energy efficiency; government policy; household lighting; social practices.

Reference to this paper should be made as follows: Crosbie, T. and Guy, S. (2008) 'En'lightening' energy use: the co-evolution of household lighting practices', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.220–235.

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1 Introduction

The UK Government is committed to making an ambitious 60% reduction in UK Carbon Dioxide (CO_2) emissions from 1990 levels by 2050. This demands a reduction in emissions of CO_2 per head from around 3 tonnes of carbon per year (tC/a) in 1990 to around 1 tonne of carbon per head in 2050. Therefore, the need to identify effective measures to promote carbon reduction is urgent. The built environment – both domestic and commercial – is a significant arena for energy consumption and contributes substantially to emissions of greenhouse gases in the UK. Tackling energy use in this sector through the design and development of low carbon buildings is a policy priority for the UK Government (DTI, 2002), and forms part of wider policies and initiatives promoted by the European commitment to reduce household energy consumption (European Council, 2003; European Commission, 2005a).

The search is on for the technologies that might contribute to the mitigation of carbon use, and Compact Fluorescent Light Bulbs (CFLs) represent a proven, readily available technology that could deliver substantial energy savings in the residential sector.[1] As a result, lighting is often a preferred target for household energy-saving campaigns and policies (Mills, 2002). However, in the face of an early policy focus on CFLs as a means to reduce household energy consumption (see Mills, 1993), the amount of energy used to light homes continues to rise (Palmer and Boardman, 1999; Mills, 2002). It is estimated that the total amount of energy used for domestic lighting in the UK grew 63% between 1970 and 2000, and by 11% between 1990 and 2000 (DTI, 2002). The latter increase occurred despite the UK Government's subsidisation of CFLs, which led to the distribution of almost 17 million of these energy-efficient light bulbs between 1994 and 2000 (Ofgem/EST, 2003).

In the UK, the main policy approach to reducing the energy consumed by household lighting has been the subsidies for energy-efficient CFLs through the electricity industry (Boardman et al., 2005, p.53). There are also a range of policies and initiatives designed to stimulate the market for dedicated energy-efficient lighting fixtures and fittings[2] (MTP, 2006). These include building regulations that set limits on the energy efficiency of lighting in domestic buildings and the DEELs programme, which seeks to rebate the cost of supplying energy-efficient light bulbs with the sale of dedicated energy-efficient lighting fixtures and fittings. However, despite these policy innovations, it is predicted that the energy used to light homes in the UK will rise a further 20% by 2020 (MTP, 2006).

According the Department of Trade and Industry (DTI), the increase in the energy used to light homes is largely due to the shift away from lighting rooms by single ceiling bulbs towards multi-source lighting from wall and table lamps as well as multi-ceiling lights (DTI, 2002). This suggests that people are changing their household lighting practices in ways that increase the energy used by those practices.

As part of its commitment to reduce household energy consumption, the UK Government, through its Engineering and Physical Research Council, is currently funding research into energy consumption and buildings under the Carbon Vision programme.[3] One of these research projects is being conducted by the Carbon Reduction in Buildings (CaRB) consortium.[4] The CaRB project acknowledges that reducing carbon emissions from buildings requires understanding both the technical and social dimensions of energy use. Toward this end, part of the CaRB team located at the University of Manchester is examining the social and cultural influences on home energy use. The research presented in this paper, exploring household lighting practices, forms part of this study.

In order to explore the factors framing the increase in the energy used to light homes, this paper examines household lighting practices in the UK using in-depth interview data from 18 respondents conducted in March 2006. Snowball sampling was used to recruit the 11 women and 7 men that took part in this study. All but two of the interviewees are owner occupiers, and most have a household income at or above the UK national average of 22,000 pounds per annum. Two of the respondents are single and live alone, the other 16 respondents live with their spouse or partner and 7 of these respondents have children living at home. All the interviewees live in single family houses in urban areas.

The interview guide approach was taken in this research[5] (Patton, 1990), and as is usual when using this approach the interviews were recorded and later transcribed for analysis. The interviews took place in respondents' homes allowing the interviewer to confirm some of the respondents' responses. The length of the interviews varied, between 40 min and an hour and a half, depending upon the length of the responses given by respondents. The interviews were designed to uncover how the research participants currently light their homes, how this may differ from the ways they lit their homes in the past, what type of household lighting they aspire to in the future and why they made particular lighting choices. It is hoped that a better understanding of these factors can provide a sound basis from which to evaluate policy options and assess potential energy savings for this important aspect of household energy consumption. Our aim in this paper is to start to outline an alternative approach to exploring and explaining home energy use using lighting as a case study as a contribution to the wider debate on sustainable energy systems.

The remainder of this paper is split into three sections. To contextualise the arguments presented, the first section introduces the reader to the contribution of the social sciences within household energy studies and discusses the concept of household lighting as a social practice. In doing so, this section of the paper highlights the importance of the cultural and social meaning of lighting in shaping household lighting practices. The second section of this paper presents an analysis of the interview data. This section illustrates how and explores why research participants' household lighting practices are changing and the effects of these developments on the amount of energy used to light homes. In the third and final section, the policy implications of the research findings are outlined.

2 Social science and household energy studies

CFLs are one of the many innovative solutions to the question of 'how people can be more efficient' developed by engineers and other natural scientists. However, engineers and other natural scientists rarely seek to ask 'why people are not more energy-efficient, when clearly it is technically possible for it to be so?' Raising this question suggests other questions about whether the right technologies and policies are being developed to reduce energy consumption (Shove et al., 1998; Guy, 2004; Chappells and Shove, 2005). These types of questions have more commonly been raised within the social sciences. For example, research within economics has attempted to address the question of why people are not more energy efficient with reference to market barriers to energy efficiency. Or in other words, economists have attempted to come up with the reasons why energy markets do not operate in the most efficient manner. From a sociological perspective, the problem with the approach taken by many economists is, on the whole, they assume the choices individuals make with regard to energy consumption are more or less rational, in the sense that they assume people will choose the most efficient option available because it is in their economic interest to do so (Shove et al., 1998). However, as neatly illustrated by the slow uptake of CFLs,"[i]t is well known that a lot of energy efficiency improving measures could be realised from a technical point of view and that they would be economically profitable, yet they are neglected"(Weber, 1997, p.833).

Building on the work carried out by economists, researchers within psychology have attempted to account for how and why people might deviate from expected economic rationality (Lutzenhiser, 1992, p.52). The main focus of this work has been the attitudes towards energy consumption and saving (Aune, Thomas and Sorensen, 2002, p.9). However, it has proved very difficult to predict the linkage between the attitudes towards energy-saving and actual behaviour, and recent psychological research examining home and energy use suggests "that using only attitudinal variables, such as values, may be too limited to explain all types of environmental behaviour" (Poortinga, Steg and Vlek, 2004, p.70).

In the late 1980s, both sociologists and psychologists began to argue that both rational and attitudinal approaches are severely flawed (Lutzenhiser, 1992, p.53). The problem with these approaches, it was argued, is that they both consider energy purchase and use in self-contained individual or household 'units' detached from their socio-cultural context – and thus separated from much that is potentially explanatory (Fujii and Lutzenhiser, 1992; Lutzenhiser, 1992; Strang, 1997; Wilhite, 2001; Wilk, 2002; Guy, 2004). Or in other words, they neglect that household energy consumption is a situated social practice – in that uses of household appliances are mediated and filtered through existing cultures and conventions to produce particular forms of cooking practices, heating practices, lighting practices and so on (Shove et al., 1998; Warde, 2005). Reviewing this work Loren Lutzenhiser found "a consensus in the literature" that to understand the socio-technical complexity of energy-saving action, policymakers must concern themselves more directly with "the social contexts of individual action" (Lutzenhiser, 1993, p.262). As Lutzenhiser points out:

> "While the physical-technical-economic model assumes consumption to be relatively homogenous and efficiency to be driven by price, the empirical evidence points towards variation, non-economic motives, and the social contexts of consumption. Economics can supply normative guides regarding when investments would be economically desirable, but it tells us little about how persons actually make economic decisions" (Lutzenhiser, 1993, p.269).

2.1 Household lighting as a social practice

In contemporary studies, the use of practices as an analytical framework is emerging as a theoretical and empirical approach that bridges between theories of consumption, technology and society (Shove, 2004; Spaargaren, 2004; Hand, Shove and Southerton, 2005; Warde, 2005). These approaches are informed by the understanding that "[w]hen people use goods and services, they do not consider their activities to be about' consumption', but rather to be about doing things like cooking, travelling or cleaning" (Warde, 2005, p.150, note 6). Consumption is so to say 'derived' from practices, or as

Warde puts it, "from the point of view of a theory of practice, consumption occurs within and for the sake of practices" (Warde, 2005, p.145).

From this perspective, energy consumption in the home is the outcome of numerous household energy consuming practices such as cooking, lighting and heating. Each of these domestic practices involves a suite of technologies and numerous culturally informed decisions made by individual householders, both of which are shaped by particular institutional arrangements. The key analytical move here is that research on energy consumption focuses not on decision-making but on the daily routines within which cooking, lighting, heating and bathing, etc. are enacted. Seen this way, it is "practices, which are logically and ontologically prior to action [that] steer consumption" (Warde, 2004, p.5).

Following the above argument, the social practice of household lighting can be understood as involving the acquisition,[6] installation and use of lighting technologies in the home. The technologies used in household lighting practices include light bulbs and light fixtures, which are part of the built fabric of the home, standalone lighting appliances (such as table lamps, reading lamps and standard lamps), automated lighting technologies (such as security lighting) and lighting controls (such as dimmer switches). The decisions involved in household lighting practices include choices over both occasional actions (such as installing new light fixtures or buying a new lamp) and routine actions (such as setting lighting timers and switching lights on and off). The institutional arrangements that shape household lighting practices include the energy supply regulations, the structures of energy supply and distribution businesses, building regulations, the markets for light bulbs and light fittings and the aims of Government policies and initiatives. Practices result from the active and creative co-production of these objects and processes within localised and dynamic settings.

A seminal exemplar of research on practice carried out in Japan and Norway helps us to conceptualise how particular cultures mediate household lighting practices (Wilhite et al., 1996). This work found that

> "heating and lighting have important symbolic value [being used] in combination to create what the Norwegians call cosiness, a state of comfort that is practically mandatory for Norwegian living rooms … [and that] the strong social significance of cosiness leads to overheating and over lighting as insurance against social failure" (Wilhite et al., 1996, p.10).

In Japan aesthetic considerations were found to be no less significant than in Norway, but they took a very different form. As a result, Japanese living rooms are exclusively lit by central ceiling lamps; brightness is preferred and fluorescent lighting is the norm. This research also found diametrically opposing preferences for lighting in Japanese and Norwegian bathrooms and kitchens. In Norway fluorescent lights are common in both, whereas in Japan these are the only places in the home where one usually finds incandescent lighting.

This research neatly illustrates that the use of lighting fixtures and fittings is mediated and filtered through existing cultures and conventions to produce particular forms of household lighting practices. However, it does not address the question of how household lighting practices come to change and what the consequences are for the levels of household energy consumption. It is these interests which underpin this paper and to which we turn now.

2.2 How do social practices change?

While it makes sense to see the choice and use of household lighting as a situated social practice, this does not immediately help us to understand how lighting design and use changes over time. The study of Shove and Pantzar (2005) on Nordic walking (a form of speed walking using two specially designed sticks) is particularly helpful when trying to understand this process. This study illustrates how new social practices arise out of the integration of images, artefacts and forms of competence. In the case of the recent vogue for Nordic walking in Norway, this involves the integration of images of health and fitness with the production and advertising of specialised walking sticks (designed and marketed specifically for Nordic walking), and the availability of specialised training in Nordic walking. The success of the process depends crucially upon translating existing images of walking with sticks that are associated with infirmity, with a new image of walking with sticks as fun and healthy (Shove and Pantzar, 2005, p.48). From this point of view, when companies promote products, which suppose the parallel existence of meaningful social practice, in effect they promote the diffusion of the elements or ingredients out of which new practices emerge in a form of co-production.

Critically, the exporting of Nordic walking has largely failed in the UK, despite the availability of the sticks and training courses. Shove and Pantzar (2005) attribute this not to technological failure, but rather to an inability to successfully translate British ideas of walking as a non-adrenalin recreation into a more Scandinavian, adrenalin-focused mode of walking more commonly described in the UK as trekking. Coupled with a British reserve and resistance to 'looking silly', Nordic walking faces an uphill battle for acceptability in the UK. This is not, they argue, a failure of technology transfer, but rather a failure to integrate new technologies and techniques of walking into existing practices. The challenge for those wishing to export Nordic walking is then not one of diffusion, but one of successful reinvention in diverse cultural settings.

Following this argument, we can conceptualise changes in household lighting practices as arising from the co-evolution of changing images of household lighting, the development of new household lighting appliances and the promotion of new lighting designs for homes. From this perspective, when those involved in the design and marketing of lighting promote particular lighting products and lighting schemes, they are in effect promoting particular styles of household lighting practices, which are picked up and re-translated by consumers in their own homes, in turn reshaping the energy performance of domestic buildings.

To begin to explore this process, the next section looks at the images and methods of household lighting promoted in the UK. This paper then presents the empirical research and explores whether these images and methods of household lighting are influencing the ways in which lighting appliances are used by the householders that took part in the study which underpins this paper.

2.3 The promotion of lighting practices

Picking up on the Scandinavia lighting aesthetic noted by Wilhite et al. (1996), the lighting practices promoted in the UK and across Europe are a variant of the Norwegian approach to lighting living rooms using multiple appliances to create a cosy homely atmosphere. For example, the 'BBC Homes' website advises householders to light their living rooms with "table lamps dotted around the outside edges of the room on shelves and tables, [claiming that] [t]hey'll radiate light inwards, making the room feel spacious yet cosy" (BBC, 2006).

The BBC echoes the international Swedish furniture manufacturer and retailer IKEA. Its marketing material, states that "often a combination of different types of lamps is required to create a comfortable light" and you should "move the lamps about in the room; vary them, until you find a lighting scheme that is as functional as it is cosy and relaxing" (IKEA, 2006a) IKEA's marketing material goes on to suggest "mixing different kinds of light can create a cosy and welcoming atmosphere and encourage us to enjoy our homes more" (IKEA, 2006b). OSRAM, one of the two largest lighting manufactures in Europe, claims in its promotional material that "[p]roper lighting is essential for creating a cosy atmosphere" and that you can "[m]ake your home that little bit cosier with OSRAM RELAX" [a type of incandescent bulb] (OSRAM, 2006).

The household lighting practices currently promoted widely in the British media extend the multi-appliance approach to lighting beyond the living room to all areas of the home. In the UK's best selling homes style magazine, 'Ideal Home', an article entitled 'how to select lighting' claims that

> "to light every room successfully, you need to layer lighting by mixing pendants, wall lights and floor to table lights … For atmosphere, go for table lamps with pale shades for a warm glow, or dark versions to direct pools of light down onto the table and a floor lamp for eye level lighting" (Ideal Home, 2006a, p.34).

Other articles in this issue of 'Ideal Homes' advise readers, to "light up your home" with Tesco's new range of designer lighting (Ideal Home, 2006b, p.19), and to "use light to set the mood" when creating a relaxing space (Ideal Home, 2006c, p.100).

Another UK homes style magazine, '4 Homes', advises on the importance of lighting in kitchens claiming

> "pendant lights will look more relaxed and provide a cosy glow over the kitchen table; and for atmosphere and to give the units a feeling of depth at night – important in a narrow kitchen – lights can be fitted in glass-fronted units" (Brownlee, 2006, p. 43).

The 'BBC Homes' website advises householders renovating their bathrooms to "[s]tud the ceiling with several low-voltage spotlights or downlighters, which wash the walls with light" (BBC, 2006).

In a similar way that the success of Nordic walking depended crucially on translating the image of walking with sticks from that of infirmity to health and fun, the shift from light-bulbs as providing basic, task-based visibility to 'washing' walls with light can be seen as an attempt to transform lighting practices with dramatic consequences for energy use.

3 Changing household lighting practices

In this section, we explore whether the images and methods of household lighting discussed above are reflected in the lighting practices of the householders that took part in the research.

In line with the multi-appliance approach to lighting homes, all of the interviewees stated that they currently use more lighting fixtures and fittings in their home than in the past. Comments such as "years ago we only had one light in the middle of the room [and] now we have at least three or four in each room" and "when I was a girl we only had one light in the ceiling and maybe the odd lamp, I think we simply have more lights now" were common.

When respondents were asked why they choose to have more lighting in their current home than in the past, most said they had changed the way they light certain rooms in their home to create a "better atmosphere" and give them more "flexibility" to change lighting "to create different moods" and accentuate different parts of their home.

All but one of the interviewees said that the style, design and flexibility of their household lighting are now more important than they were in the past. The following comments are representative of interviewees' statements about the changes in the importance of household lighting:

> "years ago when we all had single lights we didn't know any different, but I think now having adequate lighting of a suitable style to create the right ambiance is important, the look of lights is also important – you know if it fits into the décor of the room" [single male in his late fifties].

> "I like to have flexibility in lighting to be able to dim the light by turning off the main lights and having lamps or I like minimal lighting in the ceiling using a dimmer switch, as you can see here in this room [the dining room] … in the living room I have flexibility created by the different lamps I have in there" [female in her early thirties living in a five person household].

> "I think the change from one light in rooms started years ago when we got a television and you needed a side light beside the television. Now I don't like ceiling lighting, I like more side lighting, I find it calming. I don't like light coming down on top of me. I like the lighting arranged to show off different bits of the house and ornaments" [female in her early sixties living in a two person household].

The interviewee claiming the lighting in his home had "never been important to him" lives with his wife and three young children. This interviewee went on to say that the lighting in his home is very important to his wife. He said his wife made all the decisions concerning lighting in their household and his only input was to comment if he disliked the lighting she purchased, in which case she would be sent to change the new light fitting for one he found more "agreeable to use and look at". This suggests that this interviewee did find some aspects of the design and style of his household lighting important.

Six of those interviewed said that they were unhappy with their current lighting in their living rooms and would like to install new light fixtures and fittings. Four of these respondents said that they planned to change their living room light fittings in the near future. When asked what kind of lighting they would like and where they got the idea for that particular style of lighting, it became evident that the lighting promoted by television programmes and housing style magazines played a role in the respondents' decision-making. For example, when asked what style of lighting she was planning to have in her living room, one interviewee replied,

> "I quite like the idea of track lighting but again it uses halogens and is not very energy efficient, but I have looked at those and thought I would love those. I would like to have little silver lines that you move your lights along, so that if you put a new picture up or something you can move the light to shine on it and it can create a lot of different moods without having to change your lighting".

When asked where she had seen this style of lighting the respondent replied

> "it was in magazines and things like that mostly … My mam buys home and garden magazines, I wouldn't know which one I saw the track lighting in, but we do look at them for ideas" [female in her early thirties living in a three person household].

Another interviewee when asked what kind of lighting she would like in her sitting room replied, "I think I would like some really nice, beautiful designer fancy lamps and touch wall lighting where you touch them and they come on". When asked where she had seen the type of lighting she would like the respondent replied,

> "the wall touch lights I have only seen on the television, it was one of those renovation programmes where they get a designer in to do it all for them" [female in her early forties living in a three person household].

Another of the respondents who was planning to change their living room lighting, when asked what kind of lighting she would have in an ideal world replied,

> "I need bright light as I get older, I would also like it to have some style [and] it is difficult to match bright light with style but you can get designers to help you with that kind of thing today, I have seen it on the TV, and in an ideal world I think that is what I would do" [female in her late fifties living in a two person household].

The role played by the promotion of lighting design in shaping household lighting practices was also evident in interviews where respondents had stated that they had strong environmental concerns and tried to use environmental criteria in their lifestyles. It might be thought that in the case of household lighting, a person with the intention to follow strictly environmental criteria in their lifestyle would act in accordance with those principals by using CFLs – a readily available efficient lighting technology. However, the two interviewees expressing the strongest environmental concerns did not use energy-efficient light bulbs throughout their homes but opted for multi-bulb halogen light fittings in many of their rooms.

One of the interviewees expressing strong environmental concerns (a female in her early thirties living in a two person household), in accordance with these concerns spent considerable amounts of time and money sourcing and buying energy-efficient white appliances for her kitchen. She also recycled household waste and made sure her household appliances were switched off at the wall to avoid the energy used by standby. However, she had installed multi-bulb halogen light fittings, with standard halogen light bulbs, in her kitchen-diner and living room. When questioned on the issue she said, "I was fully aware when I bought them that halogen lights are not really environmentally friendly or ecologically sound, it was a specific style choice". Elsewhere in her home, this interviewee had replaced standard incandescent bulbs with CFLs in accordance with her stated concerns for the environment. When asked why she had chosen to use multi-bulb halogen lights in her kitchen-diner and living room she said, "my partner designs bathrooms and kitchens to be honest when I have gone to see finished jobs the right lighting is the finishing touch".

Another interviewee (in her late sixties living with her husband and adult daughter) also expressed strong environmental concerns. At the time of the interview she was in the process of sourcing alternative energy technologies for her second home. She also recycles household waste, uses environmentally friendly household cleaning products, and has a wood burning stove to supplement her heating and hot water needs. However, she had recently installed multiple recessed halogen light fittings in her two bathrooms, kitchen and main bedroom. When questioned about this choice of light fittings she said, "I know they use a lot of energy, but I need bright light now I am getting older and I like they way they look, they give a good effect". In common with the interviewee discussed earlier, this respondent had replaced standard incandescent bulbs with CFLs, in this case she had done so some 8–10 years ago. However, when renovating her home and replacing her kitchen and bathrooms some 4 or 5 years ago, she had opted for multiple recessed halogen lights. When asked why she had chosen this particular style of lighting the interviewee replied,

> "I think I was probably influenced by changing fashions, it's old fashioned now to have single central lights and when I was choosing the new kitchen the lights were part of the package and I just took their advice. When we came to do the bathroom I decided to have them in there as well because I like them so much in the kitchen and so on".

The selection of multi-bulb halogen light fittings for their kitchens and bathrooms by the two interviewees discussed earlier were far from isolated. Most of those interviewed had either selected multi-bulb halogen lights for their kitchens and /or bathroom or said they would like to have multi-bulb halogen lights in at least one or the other. However, the replacement of standard incandescent bulbs for CFLs was more unusual. Only five of those interviewed, including the two environmentally aware respondents discussed earlier, used more than one or two CFLs in their home.

It is well known that

> "[e]ven individuals who state the intention to follow strictly and frequently environmental criteria that form the foundational principles of their lifestyle will act against these intentions at certain times and under certain circumstances in some segments of their lifestyles" (Spaargaren, 2004, p.18).

However, it is surprising that respondents with strong environmental concerns and who act in accordance with these concerns in many aspects of their household energy consumption do not do so with lighting. Light bulbs are replaced frequently and replacing standard household incandescent light bulbs with energy-efficient light bulbs has a much shorter payback period than other environmentally friendly household purchases – such as replacing inefficient household white goods with more energy-efficient ones. It is also relatively simple to do. However, the framing of apparently rational choices within wider lifestyle practices of home improvement and creation of mood and affect highlights the poverty of viewing lighting choices as simply a process of economic calculation.

3.1 Increasing energy consumption

The changing lighting practices of those who took part in the research clearly embrace a multi-appliance approach to household lighting. In this sense, the research confirms the assessment of the DTI that increases in the energy used to light homes is the result of the shift away from rooms lit by single ceiling bulbs towards multi-source lighting from wall and table lamps as well as multi-ceiling lights (DTI, 2002). The findings presented here also correlate with earlier research (Boardman et al., 2005, p.56), which indicated that the uptake of energy-efficient light bulbs in the domestic sector is slow despite the considerable subsidisation of these light bulbs by the UK Government.

More fundamentally, the evidence from the interviews also confirms that household lighting practices are inextricably interwoven with images of stylish, cosy and comfortable homes as portrayed by household lighting promoted in the home improvement and the lighting industries advertising media. Thus, the evidence from this research certainly illustrates how the promotion of household lighting design plays a considerable role in shaping the lighting practices of those that took part in the research.

4 Changing lighting practices and government policy

As discussed in the introduction, the main policy approach in the UK to reducing the energy consumed by household lighting has been subsidies for energy-efficient CFLs though the electricity industry (Boardman et al., 2005, p.53). This approach is ineffectual as a standalone initiative, as it does not prevent consumers from returning to the use of energy intensive incandescent light bulbs at the end of the lifespan of subsidised CFLs (Palmer and Boardman, 1999; Boardman et al., 2005). Therefore, "[t]he ultimate focus of any [government] strategy must be a move towards dedicated fixtures, so that the savings are certain and there can be no reversal to incandescent bulbs and higher consumption" (Palmer and Boardman, 1999, p.67).

In the face of this critique, the UK Government has made some tentative steps to stimulate the market for energy-efficient light fixtures and fittings. These include building regulations that demand the use of a limited number of dedicated energy-efficiency light fittings in domestic buildings. However, this is argued to be having a minimal impact as the lack of stylish dedicated energy-efficient light fittings and fixtures is leading those who buy new houses to replace the energy-efficient light fittings with standard light fittings using incandescent bulbs, which they find more aesthetically pleasing (Building News, 2005).

Government efforts to stimulate the market for dedicated energy-efficient light fittings and fixtures also include a programme called 'DEEL', which seeks to rebate the cost of supplying energy-efficient light bulbs with the sale of dedicated energy-efficient lighting fixtures and fittings. There have also been efforts to stimulate the design of dedicated energy-efficient light fittings and fixtures through design competitions. These include the UK Student Lighting Design Competitions involving the Energy Saving Trust (EST) and the European Design Competition for dedicated energy-efficient luminaries. However, these competitions have to become regular, and known industry events to be effective and to date this is not the case (MTP, 2006).

The UK Government's current approach of subsiding the market for dedicated energy-efficient light fittings and fixtures is underpinned by the idea that if energy-efficient lighting fixtures and fittings are readily available, householders will use them. As illustrated by the slow uptake of numerous energy-efficient household appliances including CFL's, this is rarely, if ever, the case. To significantly increase the use of energy-efficient lighting in the domestic sector, it will be necessary to introduce stringent regulations into lighting markets. Ideally, these would ensure all light fittings and fixtures sold in the UK are dedicated energy-efficient fixtures and fittings that use CFLs or other energy-efficient light bulbs such as Light-Emitting Diodes (LEDs).

So far, so efficient. However, to reduce the amount of energy used in household lighting, policymakers have to address both the efficiency of household lighting and the increasing numbers of lighting appliances used in homes. For example, CFLs are on average four times more efficient than incandescent bulbs, but the replacement of a single lighting appliance using an incandescent bulb with four or five lighting appliances using CFLs will counteract the amount of energy saved by switching to energy-efficient lighting. This is a more complex policy problem as it involves persuading householders to change their lighting practices in ways which decrease the amount of energy they use to light their homes. Or in other words to simply use less-electric lighting.

One seemingly obvious solution to the problem of how to reduce the amount of electric lighting used to light homes is to encourage the use of natural lighting. Here, as with electric lighting, the interior design industry plays a role in shaping the way in which householders utilise natural light. Pale colours reflect light back into a room, while dark colours adsorb light. On a positive note, the UK home improvement and advertising media currently advocates pale colours for carpets and walls to make the best use of the natural light in a room.[7] However, replacing the use of electric lighting with natural lighting is not as simple as painting walls cream and fitting new carpets and curtains. The problem is that the waste of energy by the use of electric lighting during the day is usually the result of poor building design and/or lack of windows (Jenkins and Muneer, 2003, p.965).[8] It must be noted that

> "[t]he increased emphasis on energy efficiency as a result of global warming has unfortunately led to forms of building design and construction where there has been reduced daylighting in domestic buildings. With windows as the main source of heat loss from buildings there has been a tendency to reduce their size with some encouragement from national building regulations. In addition the replacement of single glazing by double or double low-eglazing has led to a reduction in transmitted daylight between 10–25% (Wilson and Brotas, 2001, p.27).

The discussion surrounding the use of natural daylight in housing neatly illustrates how those involved in the design of domestic buildings, as well as those involved in the design and marketing of domestic lighting, shape household lighting practices. This suggests a need for joined-up thinking in the development of policies and initiatives designed to reduce household energy consumption. Recently, there have been some moves in this direction at the European policy level. For example, the European Parliament adopted a directive on the eco-design of energy-using products in April 2005, which aims at improving the environmental performance of products throughout their life cycle by systematic integration of environmental aspects at the earliest stage of their design (European Commission, 2005b). The problem with the eco-design directive is that most of its initiatives focus on improving the energy efficiency of the product and / or disposal of the product at the end of its life cycle with little attempt to understand the practices that shape energy use, which are an essential element of developing and marketing energy-efficient products.

The work presented here has built on the findings of earlier research (Wilhite et al., 1996) to further illustrate that lighting is intrinsically linked to cultural factors such as 'mood' and 'well-being', which need to be considered when designing and marketing energy-efficient lighting. More significantly, it has also demonstrated how lighting choices made by householders tend to co-evolve with the household lighting practices portrayed by the media. This indicates that policies which seek to promote energy-efficient household lighting must not simply seek to support the market for dedicated energy-efficient household lighting fixtures and fittings; they must also enter into dialogue with those involved in the design, production and marketing of household lighting in order to identify the energy and carbon implications of new forms of lighting design. In this way, the support of lighting designers, manufacturers, advertisers, sales people should be enlisted to demonstrate that environmentally friendly lighting schemes using a reduced number of appliances can be stylish, or in other words sometimes less is more.

4.1 Final thoughts

It has been argued "that when the social practice of inhabiting a house is taken as a starting point the possibilities for householders to green their consumption can be said to be determined to a large extent by the green alternatives made available" (Spaargaren, 2004, p.20). Our aim in this paper has not been to argue against further technological research on energy-efficient lighting, or to abandon advice and subsidy-based policy initiatives. We would argue though, that it is not only the green alternatives made available to consumers that determine the possibilities for householders to green their consumption but also the way in which those alternatives are presented or marketed to consumers. Therefore, if the amount of energy used to light homes is to be reduced, then new 'sustainable' forms of lighting practice need to be developed and promoted. This means looking beyond technologies and decision-making as two distinct realms of activity. Our research that focuses on lighting 'practices' offers what Warde suggests is a "distinctive perspective, attending less to individual choices and more to collective development of modes of appropriate conduct in everyday life" (Warde, 2005, p.146).

Acknowledgements

This work forms part of the Carbon Reduction in Buildings (CaRB) Consortium, which has five UK partners: De Montfort University, University College London, Reading University, Manchester University and Sheffield University. They are supported by the Carbon Vision initiative, which is jointly funded by the Carbon Trust and the Engineering and Physical Sciences Research Council, with additional support from the Economic and Social Research Council and the Natural Environment Research Council. The partners are assisted by a steering panel of representatives from the UK industry and government.

References

Aune, M., Thomas, B. and Sorensen, K. (2002) *Needs, Roles and Participation: a Review of the Social Science Studies of Users in Technological Design.* A report within the research program Smart Energy-Efficient Buildings at NTNU and SINTEF 2002–2006, cited on 20 May 2006. Available at: http://www.ntnu.no/em/dokumenter/smartbygg_rapp/User-Needs_State-of-the-Art.pdf

BBC (2006) 'Lighting: lighting living rooms', cited on 30 May 2006. Available at: http://www.bbc.co.uk/homes/design/lighting_livingroom.shtml

Boardman, B., Darby, S., Killip, G., Hinnells, M., Jardine, C., Palmer, J. and Sinden, G. (2005) *40% House,* February, The Environmental Change Institute, University of Oxford, London, cited on 1 June 2006. Available at: http://www.eci.ox.ac.uk/lowercf/40house.html#report

Brownlee, S. (2006) 'Gotta have it: an envy-inducing kitchen', *4 Home*, June, pp.42–47.

Building News (2005) 'Building regulations present market opportunities', *Building News*, 24 August, cited on 20 May 2006. Available at: http://www.azobuild.com/news.asp?newsID=1436

CEETB (2005) *Comments of CEETB on the Green Paper on Energy Efficiency or Doing More With Less*. European Technical Contractors Committee for the Construction Industry, Brussels, cited on 23 May 2006. Available at: http://www.ceetb.org/Position%20paper/Green%20paper%20on%20energy%20efficiency.pdf

Chappells, H. and Shove, E. (2005) 'Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment', *Building Research and Information*, Vol. 33, pp.32–40.

DTI (2002) *Energy Consumption in the UK*, Department of Trade and Industry, London, cited on 21 May 2006. Available at: http://www.dti.gov.uk/energy/statistics/publications/energy-consumption/page17658.html

European Commission (2005a) *Doing more with less: Green Paper on Energy Efficiency*, cited on 28 May 2006. Available at: http://ec.europa.eu/energy/efficiency/doc/2005_06_green_paper_book_en.pdf

European Commission (2005b) *Press Release Commission welcomes the Adoption of the Directive for Environmentally Friendly Design of Energy-Using Products*, cited on 2 November 2006. Available at: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/05/427&format=HTML&aged=0&language=EN&guiLanguage=en

European Council (2003) 'Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings', *Official Journal of the European Communities*, Vol. 4, cited on 19 May 2006. Available at: http://europa.eu.int/eurlex/pri/en/oj/dat/2003/l_001/l_00120030104en00650071.pdf

Fujii, H. and Lutzenhiser, L. (1992) 'Japanese residential air-conditioning: natural cooling and intelligent systems', *Energy and Buildings*, Vol. 18, pp.221–233.

Guy, S. (2004) 'Consumption, energy, and the environment', *Encyclopaedia of Energy*, Vol. 1, pp.687–695.

Hand, M., Shove, E. and Southerton, D. (2005) 'Explaining showering: a discussion of the material, conventional, and temporal dimensions of practice', *Sociological Research Online*, Vol. 10.

Ideal Home (2006a) 'How to light up your home', *Ideal Home*, Vol. 171, p.34.

Ideal Home (2006b) 'Light up your home', *Ideal Home*, Vol. 171, p.19.

Ideal Home (2006c) 'Create a room for relaxing', *Ideal Home*, Vol. 171, p.100.

IKEA (2006a) 'Lighting', cited on 1 June 2006. Available at: http://www.ikea.com/webapp/wcs/stores/servlet/CategoryDisplay?storeId=7&langId=-20&catalogId=10103&cattype=top&identifier=00015_irwtree003

IKEA (2006b) 'Furnish with light', cited on 1 June 2006. Available at: http://www.ikea.com/ms/en_GB/furnish_with_light/fwl_start/index.html

Jenkins, D. and Muneer, T. (2003) 'Modelling light-pipe performances – a natural daylighting solution', Bu*ilding and Environment*, Vol. 38, pp.965–972.

Lutzenhiser, L. (1992) 'A cultural model of household energy consumption', *Energy*, Vol. 17, pp.47–60.

Lutzenhiser, L. (1993) 'Social and behavioural aspects of energy use', *Annual Review of Energy and Environment*, Vol. 18, pp.247–289.

Mills, E. (1993) 'Efficient lighting programs in Europe: cost effectiveness, consumer response, and market dynamics', *Energy*, Vol. 18, pp.131–144.

Mills, E. (2002) 'The $230-billion Global Lighting Energy Bill', Paper presented in the Proceedings of the *Fifth European Conference on Energy-Efficient Lighting*, International Association for Energy-Efficient Lighting, Nice, France, cited on 20 May 2006. Available at: http://eetd.lbl.gov/emills/PUBS/Global_Lighting_Energy.html

MTP (2006) *Policy Brief: Domestic Lighting: UK Energy Consumption of Domestic Lighting*, Market Transformation Program, cited on 20 May 2006. Available at: http://www.mtprog.com/PolicyBriefs/Stage1.aspx?intPolicyBriefID=500012&strPolicyBriefTitle=UK%20Energy%20Consumption%20of%20Domestic%20Lighting

Ofgem/EST (2003) *A Review of the Energy Efficiency Standards of Performance, 1994–2002*, A joint report by Ofgem and the Energy Saving Trust, July, London.

OSRAM (2006) 'See the world in a new light: OSRAM RELAX for an atmospheric lighting mood', cited on 20 May 2006. Available at: http://www.osram.com/products/general/incandescent/active_relax/relax.html

Palmer, J. and Boardman, B. (1999) 'Delight: domestic efficient lighting', Energy and Environment Programme, Environmental Change Unit, University of Oxford, cited on 20 May 2006. Available at: http://www.eci.ox.ac.uk/lowercf/pdfdownloads/DElightreport.pdf

Patton, M.Q. (1990) *Qualitative Evaluation and Research Methods* (2nd ed.). Newbury Park, CA: Sage.

Poortinga, W., Steg, L. and Vlek, C. (2004) 'Values, environmental concern, and environmental behaviour: a study into household energy use', *Environment and Behaviour*, Vol. 36, pp.70–93.

Property News (2006) 'Home improvements that will loose you money', 19 June, cited on 3 November 2006]. Available at: http://www.aboutproperty.co.uk/news/home-improvement/home-improvement-tips/home-improvements-that-will-lose-you-money-$442821.htm

Shove, E. (2004) 'Efficiency and consumption: technology and practice', *Energy and Environment*, Vol. 15, pp.1053–1065.

Shove, E. and Pantzar, M. (2005) 'Consumers, producers and practices: understanding the invention and reinvention of Nordic walking', *Journal of Consumer Culture*, Vol. 5, pp.43–64.

Shove, E., Lutzenhiser, L., Guy, S., Hackett, B. and Wichita, H. (1998) 'Energy and social systems', in S. Rayner and E. Malone (Eds), *Human Choice and Climate Change: Resources and Technology*, Vol. 2 (pp.291–325). Columbus, OH: Battelle Press.

Spaargaren, G. (2004) 'Sustainable consumption: a theoretical and environmental policy perspective', in D. Southerton, H. Chappells and B. Van Vliet (Eds), *Sustainable Consumption: the Implications of Changing Infrastructures of Provision* (pp.15–31). Cheltenham, UK: Edward Elgar.

Strang, V. (1997) 'Contextualising values and behaviour', Paper presented in the Proceedings of the *European Council for an Energy-Efficient Economy*, cited on 20 May 2006. Available at: http://www.eci.ox.ac.uk/lowercf/pdfdownloads/ECEEE97_VS.pdf

Warde, A. (2004) *Theories of Practice as an Approach to Consumption*, Cultures of Consumption programme (Working Paper 6), cited on 20 May 2006. Available at: http://www.consume.bbk.ac.uk/working_papers/Warde%20work%20paper%201.doc

Warde, A. (2005) 'Consumption and theories of practice', *Journal of Consumer Culture*, Vol. 5, pp.131–153.

Weber, L. (1997) 'Some reflections on barriers to the efficient use of energy', *Energy Policy*, Vol. 25, pp.833–835.

Wilhite, H. (2001) 'What can energy efficiency policy learn from thinking about sex', Paper presented in the Proceedings of the *European Council for an Energy-Efficient Economy*, ADEME, France, cited on 30 May 2006]. Available at: http://www.eceee.org/library_links/proceedings/2001/abstract/Panel2/01p2_2_052.lasso

Wilhite, H., Nakagami, H., Masuda, T., Yamaga, Y. and Haneda, H. (1996) 'A cross-cultural analysis of household energy use behaviour in Japan and Norway', *Energy Policy*, Vol. 24, pp.795–803.

Wilk, R. (2002) 'Consumption, human needs, and global environmental change', *Global Environmental Change*, Vol. 12, pp.5–13.

Wilson, M.P. and Brotas, L. (2001) 'Daylight and domestic buildings', Paper presented in the Proceedings of the *XIth National Conference on Lighting*, Bulgaria, 13–15 June 2001 Light, pp.27–32, cited on 1 November 2006. Available at: http://www.learn.londonmet.ac.uk/about/doc/brotas_bulgaria2001.pdf

Notes

[1]Compact fluorescent light bulbs (CFLs) are on average 80% more efficient than incandescent lamps and their lifetime can reach 8 to 12 times the lifetime of incandescent lamps. In addition, CFLs offer possibilities for recycling, while incandescent lamps do not (CEETB, 2005).

[2]Dedicated energy-efficient lighting fixtures and fittings are designed explicitly for use with compact fluorescent lamps, and cannot be used with any other type of lamp.

[3]See: http://www.epsrc.ac.uk/ResearchFunding/Programmes/Energy/Funding/CarbonVision/default.htm

[4]*Carbon Reduction in Buildings: A Socio-technical Study of Carbon Use in Buildings* EPSRC/Carbon Trust funded project (GR/S94377/01). For more details see: http://www.carb.org.uk/

[5]In this approach the interview is guided by an outline or list of topics; therefore, the interviewer is able to vary the wording and order of the questions. It is one of the most widely used approaches in qualitative interviewing. One of the major benefits of using this approach is that the data collected are more systematic and comprehensive than in the informal conversational interview, while the tone of the interview still remains fairly conversational and informal.

[6]The term acquisition of household lighting is used here to include not only those lighting fixtures and fittings purchased by householders but also those given by family or friends, those purchased by landlords and those installed prior to current householder living in the property.

[7]For example, dark coloured decoration is argued to devalue a home by almost 10,000 pounds (Property News, 2006).

[8]There are solutions that can be retrofitted to existing houses such as larger windows or light pipes. However, these solutions are prohibitively expensive and are not encouraged by the housing improvement media or the lighting industries advertising media.

Who uses innovative energy technologies, when and why? The case of fuel cell MicroCHP in households

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Abstract: Users can play an important role in the diffusion of sustainable energy technologies. Using a postal survey and focus group discussions, the paper explores the characteristics, motives and expectations of household users in the case of fuel cell–driven small combined heat and power plants. (Potential) users are highly educated and well off, almost exclusively male and relatively old. Their main motive is their desire to be at the forefront of technological development that they perceive to be environmentally benign. At the same time, they feel the fuel cell lacks cost-effectiveness, reliability and user friendliness. They are willing to give the immature technology a chance, but strongly point to the necessity to remedy the deficits in order to reach a mass market. They are keen on spreading the word about the novelty, and can be expected to be successful communicators. Therefore, these pioneer users are relevant multipliers and valuable partners for technology developers.

Keywords: diffusion; energy; fuel cell; innovation; micro cogeneration; pioneers; sustainability; users.

Reference to this paper should be made as follows: Fischer, C. (2008) 'Who uses innovative energy technologies, when and why? The case of fuel cell MicroCHP in households', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.236–258.

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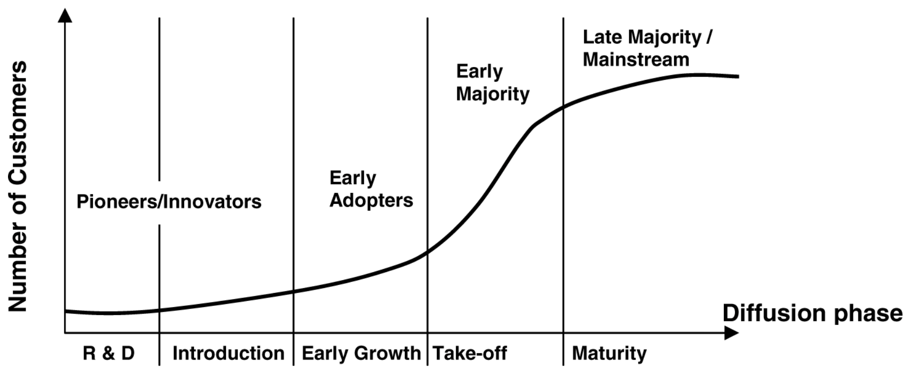
1 Introduction

One possible driving force in achieving more sustainable patterns of energy production and consumption is technological innovation. Technologies do not appear in a vacuum, though. In order to find widespread diffusion, technological novelties need a supportive social context. A tightly woven network of different actors can help or hinder their diffusion: enterprises by marketing the innovation, political actors by introducing or blocking relevant regulations, media by raising interest (or failing to do so) and consumers by taking up, commenting on and using the innovation. When we are interested in sustainable development and in the sustainability impacts of innovation, we must note, furthermore, that these actors do not only influence the success or failure of an innovation. They also shape the specific form, scope, speed and context(s) of its implementation, thereby influencing its sustainability and impact on the sustainable development of the whole system in question. Of all actors, this paper focuses on the role of users in promoting sustainable innovation.

A successful innovation and diffusion process can be portrayed as an S-curve (Villiger, Wüstenhagen and Meyer, 2000, slightly adapted by adding the R&D phase). In the course of this process, users can take on a number of different functions, partly depending on its current phase. Correspondingly, different user groups are crucial in the respective phases (Figure 1).

Figure 1 Innovation and diffusion process



Source: Villiger et al. (2000).

Users may first appear within the *R&D phase*. Usually, they show up in the form of 'user representations' – images of potential users that are constructed in developers' imagination and influence their design choices (Akrich, 1995). However, it also happens that *lead users* with very specific needs are the first to produce ideas for a novel product, develop it or even construct prototypes. Only later do commercial manufacturers jump on the bandwagon (Hippel, 2005). In the field of sustainable energy, improvements to solar water heaters, done by self-build groups of later users, are an example (Ornetzeder and Rohracher, 2006).

More often, users appear later. Near the end of the R&D phase, just before market introduction, when prototypes are being tested, *test users* voice their needs and demands, verify whether these are met by the product, and give advice and suggestions for its further development. It is possible that a new product already fails in this phase, being unable to be adapted to users' everyday needs.

In the *introduction phase*, when the innovation enters the market for the first time, the role of the users is to accept or reject the novelty. *Early adopters* embrace the novelty and pave its way into the market. Also, incremental improvements may still be made due to their suggestions.

In order to test a novel product, openness for novelties and willingness to take risks are required. Test users and early adopters therefore make up a special group that may be called *pioneers* or *innovators,*[1] and is characterised by unusual commitment, curiosity, special interest in the product and willingness to take risks. Rogers (2003) describes pioneers as controlling substantial funds (which allows them to compensate for potential losses of an investment) and as well educated (which enables them to understand the innovation). Due to their originality, though, they may be outsiders.

In the '*early growth*' phase, the product is taken up by a broader group of users who function as multipliers, spread the word and promote the innovation – the *early majority*. To succeed in this endeavour, they need to be socially integrated and have good communication skills. In the *take-off phase*, the product is taken up by substantial numbers of users – the *late majority* or *mainstream*. To succeed in this phase, the product must appeal to more 'mainstream' users who demand personal benefits and 'value for money'. They may lack the specific curiosity and willingness to take risks that characterise the pioneers. These users influence the innovation's success and its sustainability by accepting or rejecting it, by choosing different types or brands with specific features, and by their patterns of use (including intensity, frequency and time of use, individual or collective use, purpose and social context of use and symbolic dimensions). Patterns of use become even more important as more and more people use the product in the *maturity phase* and market saturation is approached.

Users may be individuals as well as firms or organisations. In principle, all the roles described above may be filled by both types alike (Hippel, 2005, p.3). However, individuals' needs, logic of action and capacities to influence the development of a product differ widely from organisations. When analysing the role of users, one must therefore specify which type of user one is talking about.

In this paper, the author is focusing on the end of the R&D phase, and examines a group of individual pioneer users of a sustainable energy technology: small combined heat and power plants (MicroCHP). The goal of my research is to find out how such pioneer users can contribute to the development and diffusion of sustainable energy innovations. Specifically, the author wants to clarify the following questions:

- Who is the potential target group for such a technology? What are their characteristics and motives?

  This question is important in order to know who must be addressed and in which way, if one wants to promote a sustainable energy technology like this.

- What do the pioneer users need from the technology? And how do they judge its performance with respect to their needs?

  To know users' needs and plot them against the real and expected performance of the MicroCHP is important for two reasons. First, it helps to identify shortcomings and potential for improvement from a user perspective. Secondly, it may reveal communication needs and gaps.

- What can users contribute to the improvement and diffusion of the technology?

  To ask this question means to consider users as active partners in the diffusion of sustainable energy solutions.

2 MicroCHP: the technology and the project

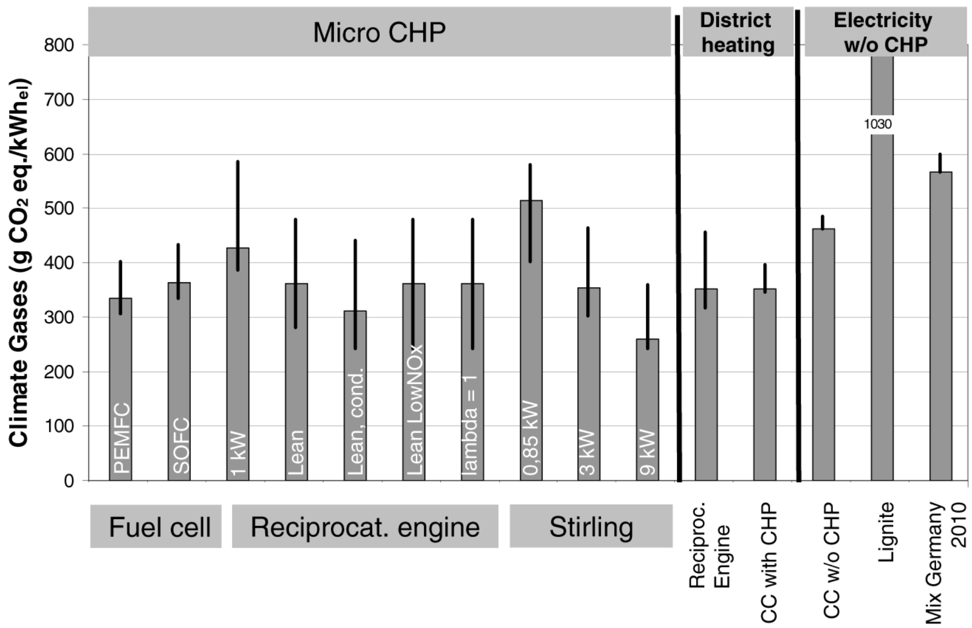
The innovation analysed here are small combined heat and power plants, suitable for individual buildings, based on fuel cell technology (in the following: fuel cell MicroCHP). MicroCHP can be based on a number of different technologies and fuels. In general, it has ecological advantages compared to centralised generation with the same fuel. However, it is not always advantageous if compared to district heating systems (Pehnt and Fischer, 2006). MicroCHP can therefore add to a more sustainable electricity system if implemented in areas with no prior district heating infrastructure. It is a rather new development that would, if implemented widely, thoroughly change patterns of production, consumption and regulation in the electricity system. Small industry, public service institutions and even private households would be able to produce electricity along with their room heating and feed it into the grid. Grid operators would have to accommodate thousands of small distributed generators. Patterns of consumption may change in order to make best use of the self-produced electricity.

Fuel cells are probably the most inspiring among the various MicroCHP technologies, sparking visions of a 'hydrogen economy' and fuelling, above all, the imagination. Fuel cells promise several environmental benefits, including extremely low emission levels and low noise (Figures 2 and 3). Still, they are in a rather immature development phase.

While several thousand MicroCHP based on reciprocating engines have already been sold in Germany, fuel cell prototypes are currently being tested in the field. In 2003, electricity utility EnBW started a field test in the German Land Baden-Württemberg. By spring 2006, 18 fuel cell home heating systems had been installed, 16 of them manufactured by Sulzer Hexis, 1 by Vaillant and 1 by European Fuel Cells. At the beginning of the test, EnBW launched an advertisement campaign in regional newspapers looking for 'pioneer households'. The response was overwhelming. Though the utility planned to test only a few prototypes, over 6,000 households volunteered. After having received a first questionnaire that reviewed the suitability of the building and gave some information about conditions and duties involved, about 1,000 volunteers remained. The deal was that the volunteer households should receive a fuel cell home heating system that functioned as a combined heat and power plant, generating electricity that could be used in the household or fed into the grid. The system was contracted, meaning that it remained the property of the power utility which was responsible for maintenance and operation. If the plant failed, the power utility was in charge to replace it or provide a substitute so that the user's supply was guaranteed at any time. Users had to pay for the heat and electricity they received from the plant. The tariffs were compatible to the average tariffs for long-distance heating. Furthermore, they had to pay a one-time 'innovation contribution' of 2,000 Euro. Pioneer users were charged with several duties, among them, to provide access for engineers and technicians for monitoring purposes.

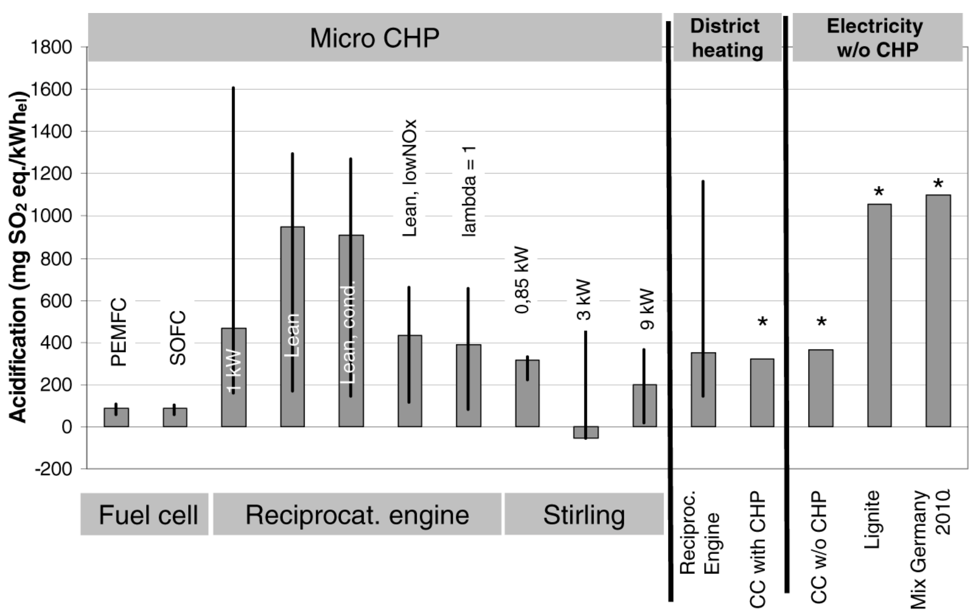
Thus, there was no financial incentive involved. The duties meant some inconvenience for the users, and it was by no means clear that the new technology would work reliably and satisfactorily. So how did the overwhelming interest come about? Who were those pioneers and what motivated them? And can that motivation be used to both improve and diffuse the MicroCHP system? To find out more, we first reviewed the literature on users of other innovative energy technologies to form some hypotheses. Later, we carried out an empirical study consisting of a number of group discussions and a postal survey. The results are presented in this paper.

Figure 2 Climate gas emissions of MicroCHP



Source: Pehnt and Fischer (2006, p.96).

Figure 3 Acidifying emissions of MicroCHP



Source: Pehnt and Fischer (2006, p.101).

3 Hypotheses about innovative energy technology users: a literature survey[2]

For a start, we reviewed empirical studies that deal with user aspects of other innovative and ecologically sound home energy technologies – namely solar heat, photovoltaics and biomass heaters. We sought out studies that deal with users' motives, experiences, attitudes or characteristics. To allow for a comparison, we focused on the last decade and on German-speaking countries. Interestingly enough, not many studies on these topics are available. Apparently, user aspects are assigned little relevance among scholars of energy technology development.

In the end, 12 studies could be found, performed in the years 1992–2003 (Hackstock et al., 1992; Genennig and Hoffmann, 1996; Greenpeace, 1996; Katzbeck, 1997; Rohracher, Suschek-Berger and Schwärzler, 1997; Karsten, 1998; Haas et al., 1999, 2001; Reif, 2000; Hübner and Felser, 2001; DENA, 2003; Polzer, 2003). Six of them dealt with photovoltaics, two with solar heat systems, two with both of these, one with biomass and one with several different renewable energy technologies. They covered topics as diverse as: number and performance of systems installed, motives and aims of the users, supporting factors and barriers, experience with the systems and satisfaction, evaluation of support schemes, attitudes on energy and the environment, sources and level of information and effects of the systems on the users' energy consumption. From these studies, we could derive some hypotheses and some open questions, relating to the research questions. The author will now sum them up and highlight the points that we wanted to clarify in our empirical study.

3.1 Who is the potential target group? What are their characteristics and motives?

Our first hypothesis fits well with Rogers' description of pioneer users in general:

- Sustainable energy pioneers are well-educated members of the upper middle class.

In our literature review, it held especially for the photovoltaics users, while some solar heat and biomass users were farmers or craftsmen. We hypothesised that this was due to the fact that these technologies had a rather 'low tech' image and were seen as suitable for 'do it yourself'. In fact, many solar heat systems in Austria have been installed by a 'Do it yourself movement' (Ornetzeder and Rohracher, 2006). Furthermore, farmers often possess their own forest, being able to supply the biomass system with wood. By contrast, we suspected that photovoltaics was seen as 'high tech' but also as an expensive, 'green' plaything which was not yet mature and therefore left to ecologists and the well-off.

We were eager to know which argument would apply to fuel cell MicroCHP. We suspected that it might attract a similar group as photovoltaics, because it is currently in an even earlier stage of development.

Our second hypothesis was a consistent finding, in as much as studies had analysed that aspect:

- Sustainable energy pioneers are well informed and have been dealing with 'door opener' technologies before.

Pioneers showed strong interest in the technology and knew much about it. Especially photovoltaics users had very often been using solar heat systems before. Apparently, the positive experience with the 'simpler' technology encouraged them to try a more 'advanced' one. We hypothesised that this would hold for fuel cell MicroCHP too.

The last hypothesis was a consistent result in all the studies.

- Sustainable energy pioneers are environmentally conscious and keen on new technology.

We suspected that this would also hold for fuel cell MicroCHP.

In spite of these hypotheses, one question remained unanswered:

- What is the relative importance of different motives?

In all studies, pioneers were motivated mainly by environmental concerns, economic considerations and/or technological interest. But the relative importance of those motives differed strongly from study to study, from sample to sample and between different methods of data collection. So what would be the most important motives in the fuel cell MicroCHP case? And how would they relate to each other?

3.2 What do the pioneers need from the fuel cell system and how do they judge its performance?

Naturally, this question could not be answered by the literature survey. Therefore, we included it in our empirical study.

3.3 What can the pioneers contribute to the improvement and diffusion of the novelty?

The literature suggested an active and competent role of the sustainable energy pioneers:

- Sustainable energy pioneers are aware of their pioneer role, communicative and willing to promote the technology.

To a certain degree, this hypothesis seems to fit badly with Rogers' opinion that pioneers might be outsiders and lack social integration. If Rogers is right, pioneers might run into a problem if they *want* to communicate but do not succeed. Therefore, we found it interesting to explore this aspect empirically for our case.

4 Fuel cell pioneers: an empirical study

4.1 Method

At the time of the study in spring 2004, only a handful of fuel cell MicroCHP had been installed. For this reason, few data on actual users were available. As a substitute, we decided to also analyse applicants for the field test, assuming that their motives would be similar to those of actual users.

One group discussion was held with the first seven actual users. On the basis of an interview guide, group members were asked about the reasons for their application, about hopes and fears regarding fuel cell MicroCHP, about preferred ownership models and about the advantages and disadvantages of fuel cell MicroCHP as compared to other electricity or heat technologies. Furthermore, three similar group discussions were conducted with, all in all, 26 applicants. For this purpose, all applicants within a certain geographic region were invited to the focus group discussion. The aim was to keep travel distance to the discussion location below 50 km. The 94 applicants living in the region were contacted by mail. About 35 applicants volunteered to take part in a discussion; 28 were finally chosen on the basis of availability at the scheduled time, of which 26 actually showed up.

Additionally, a postal survey was carried out. Half of the about 1,000 applicants who had remained after the first selection were contacted by mail, all in all 462 valid addresses. They were sent a questionnaire which, in part, dealt with similar issues as the focus group: motives for the application, requirements for home energy systems, image of the fuel cell system and assessment of its performance, sources of information and communication with others about energy topics and about the fuel cell MicroCHP. Additional information was collected on sociodemographic data, attitudes on energy and the environment, attitudes on technology, political interest and participation, values and environmental behaviour. Where possible, items and instruments from existing representative surveys were used in order to allow a comparison of the pioneer sample with the general population. Filling in the questionnaire took about 30 mins. Building on the supposedly high motivation of the applicants, no further incentives were used. About 142 applicants responded, which makes a satisfactory response rate of 30%. In the following, the author reports mainly data from the survey, which covered a broader sample and set of topics. Where possible and helpful, the data are illustrated, explained or contrasted with focus group results.

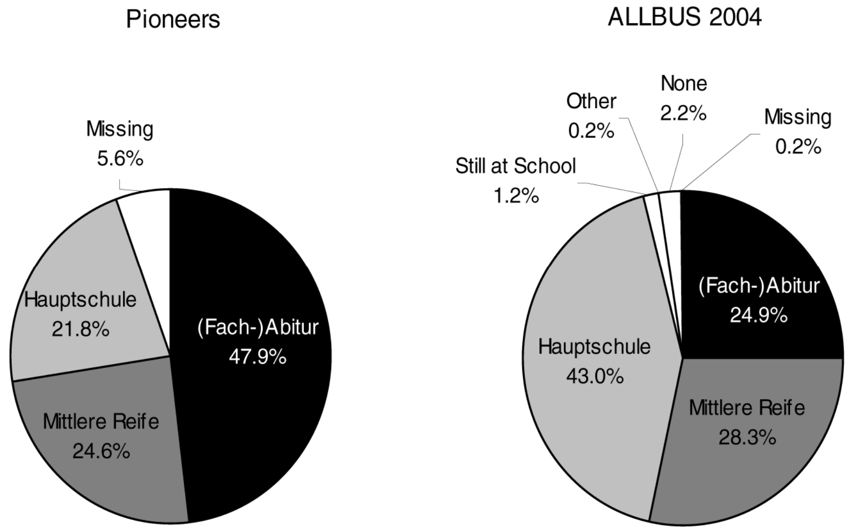
4.2 Who are the pioneers?

The first striking result is the homogeneity of the sample. The pioneers are almost exclusively men. They are relatively old, well-off and live with their families in their own homes in rural areas or small towns. They are educated professionals, very often in a technical domain. Some few figures illustrate these findings. In the postal survey, only 7 of the 142 respondents are women. In the focus groups, women lack completely.

To identify more socio-demographic characteristics, we compared survey respondents to a representative sample of the German population over 18, according to the biannual survey '*Allgemeine Bevölkerungsumfrage der Sozialwissenschaften*' (ALLBUS, 2004). The pioneers' average age is 54.9 years, as compared with 47.6 years in the ALLBUS sample. The difference is statistically highly significant. Almost 20% of the pioneers have a net monthly household income of more than 4,500 EUR. In the representative ALLBUS sample, this group makes up for only 6.6%. However, the high household income does not necessarily mean a high per capita income. The pioneers are not only especially well-off, they also have especially big families. In a pioneer household, there are 3.15 people on average, as compared with 2.64 in the general population. This means that the additional income must also feed additional people.

Figure 4 illustrates the pioneers' education: their school degrees are compared with the school degrees of the male part of the ALLBUS sample. The males were chosen because there is reason to believe that in the older age groups men in general received higher degrees than women, which may bias the comparison.

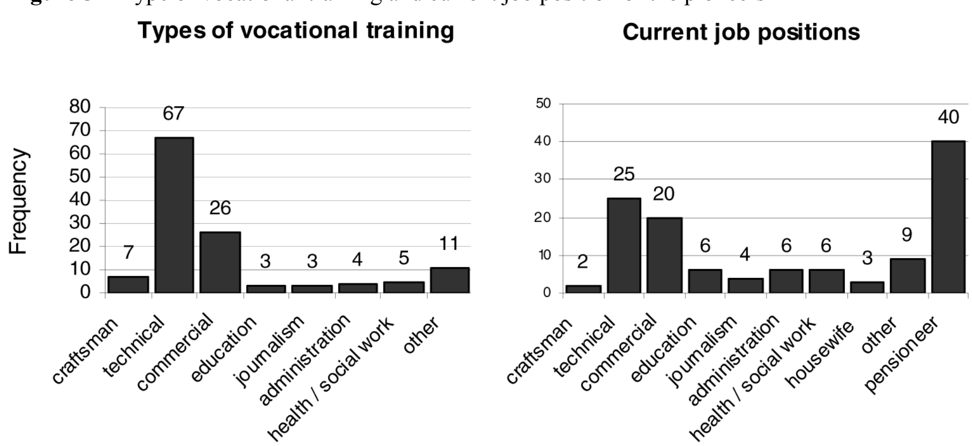
Figure 4 Education of the pioneers compared with a representative population sample



The darkest section shows the highest degrees available at German schools, the *Abitur* or *Fachabitur*; the middle section shows an intermediate degree (*Mittlere Reife*); and the lightest section the lowest degree (*Hauptschule*). It becomes apparent that especially the percentage of persons with Abitur is significantly greater in the pioneer sample. Furthermore, about 40% have a university or comparable (*Fachhochschule*) degree, which is also significantly higher than in the ALLBUS sample.

Many of them have a technical profession. Figure 5 shows the vocational training and current job position of the pioneers. The information stems from an open question; the answers have later been categorised. The numbers show the frequency of mention (multiple answers were possible). It becomes apparent how many of the pioneers have a technical training and / or work in a technical profession – but also, how many of them are already retired, corresponding to their relatively high age.

Figure 5 Type of vocational training and current job position of the pioneers



The pioneers are almost exclusively home owners (which is not too surprising, because it is the owner who has to decide upon the heating system). But an additional feature is that they also live in their own house. About 131 own the house they live in, 8 own their flat. That means they want to have the new technology for their own use, not as landlords for their tenants. Typically for home owners in Germany, they live predominantly in rural areas and small towns. About 20% live in a village with lesser than 5,000 inhabitants (as compared with only 7.3% of the general population in Baden-Württemberg, see ALLBUS, 2004). Only 4.4% live in towns with more than 100,000 inhabitants (as compared with 18.6% of the general population).

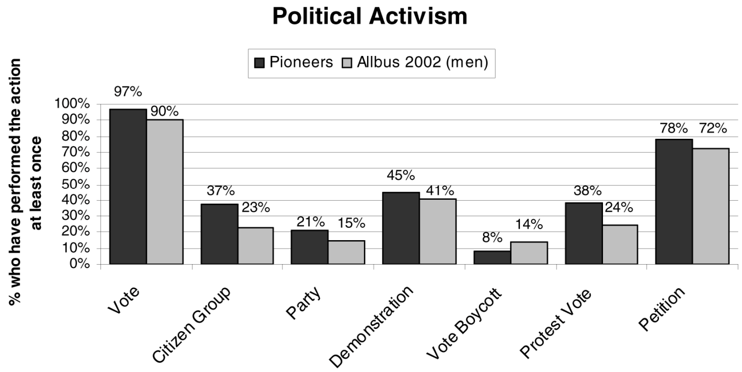
So the picture we are getting is one of well-established men owning everything that makes up for a respectable life: education, a well-paid job (or well-deserved retirement), a home and a family. Rogers' observations about the role of education and income are confirmed, though it is necessary to mention that in our case, high household income does not necessarily mean high disposable funds. Because of the relatively big households, per capita income is lowered. This means that the high household income is not so much an indicator for the ability to invest, but rather for the pioneers' affiliation with the well-situated, educated, upper middle class.

Many of the pioneers have an advanced technical understanding, which should raise their interest in technological novelties. However, the overall picture suggests a rather conservative, established lifestyle. At first sight, respondents do not convey the picture of people who would happily jump at every available adventure or experiment. So how did the fuel cells arrive at stirring so much interest? A look at the pioneers' values and attitudes might help to understand.

4.3 Some attitudes

In the survey, we explored pioneers' interest in social and political affairs as well as their attitudes on technology and the environment. Social and political interest was compared to the ALLBUS 2002 survey (ALLBUS, 2004, does not contain comparable items). One first result is that the pioneers show a keen interest in the community, both at a local level and with respect to 'big politics'. About 21.3% do volunteer community work at least once a month (as compared with 11.3% in the male part of the ALLBUS sample), 31.9% do it once a week (as compared with 20.2%) and 5.7% do it even on a daily basis (as compared with 4%). The pioneers also report high levels of political activism. Figure 6 shows the percentages of pioneers that report to have performed different types of political activism at least once, again compared with the male part of the ALLBUS 2002 sample. The different activities are: voting in an election; being an active member of a citizens' advocacy group, being an active member of a political party, taking part in a legal demonstration, refusing to vote (in order to express protest), voting for a party one would not normally consider (in order to express protest) and signing a petition. It turns out that the pioneers have performed every action more often than the male members of the ALLBUS sample, with the single exception of refusing to vote. Apparently, they feel an obligation to express their political views via the vote. All differences are significant on a 0.05 level.

Figure 6 Percentage of different political actions; pioneers compared with representative sample



Thus, the pioneers evoke a picture of persons with a keen interest in public affairs, rooted in the community and willing to do their deal for the common good, but also to stand up for their aims and interests. Focus group members confirm this view. Among them were mayors, school directors and leaders of local industry or craftsman associations. Those often regarded their fuel cell test as a public affair, wanting to use it for teaching or demonstration.

As expected on the basis of their professions, the pioneers also have a positive picture of technology and feel competent in dealing with technical issues. Table 1 shows their responses to several technology-related items. The items were rated on a scale of 1–7, with 7 meaning total agreement and 1 meaning total disagreement. The pioneers' mean responses are compared with the means of a representative sample of the population, done by the Institute for Technology Assessment and Systems Analysis ITAS (Hocke-Bergler and Stolle, 2003). Significant differences on the 0.05 level have been marked in grey.

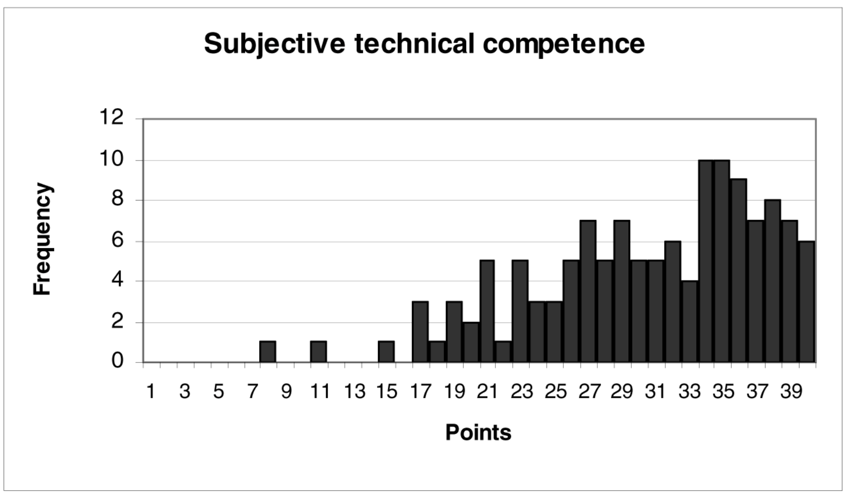
Table 1 Attitudes towards modern technology

	Pioneers	*ITAS (2003)*	*Significance*
Technology is the basis of our living standard.	6.04	5.56	0.006
Technology inevitably leads to pollution.	3.09	4.08	0.000
Technology simplifies everyday life.	5.81	5.78	0.839
Technology needs stricter control.	4.70	5.09	0.049
Without technology, everyday work could rarely be mastered.	5.72	5.67	0.766
Technology is intransparent and menacing.	2.37	3.50	0.000
Without technology, life would be more humane.	3.07	3.61	0.017
Technology enslaves people.	3.13	3.79	0.004
Technology makes life more comfortable.	6.03	5.84	0.149
Today, technology is used without investigating the consequences properly.	4.26	4.23	0.879
Technology helps to prevent catastrophes (plagues, famines).	5.18	4.92	0.189
Technology endangers man and the environment.	2.90	3.43	0.006
Technology is needed for the survival of a growing world population.	5.35	5.34	0.944

An interesting pattern shows up. The pioneers do not differ much from the general population in assessing the blessings of technology. With the exception of the item ‘Technology is the basis of our living standard’, they are very close to the ITAS sample in all positive items. However, they differ significantly when it comes to judging risks and disadvantages of technology. The pioneers are much less cautious than the general population, detecting few risks and problems in ‘modern technology’.

Figure 7 shows the responses to a test measuring subjective technical competence, that is, the confidence in one’s own ability to solve technical problems (*Kontrollüberzeugungen im Umgang mit Technik* – KUT – Beier, 1999). The pioneers were given the short version of the test, comprising eight items such as “Usually, I cope with technical problems successfully” or “I enjoy finding solutions to technical problems”. The items were to be rated on a scale from 1 (totally disagree) to 5 (totally agree). Therefore, the maximum score to be reached was 40. The table demonstrates that the pioneers reach high scores. Quite a number achieve the maximum score, meaning they are very optimistic about their technical competence.[3]

Figure 7 Subjective technical competence of the pioneers



A third topic of interest were respondents’ attitudes towards energy and the environment. We compared them with the respondents of *Umweltbewusstsein in Deutschland*, a representative German survey on environmental attitudes, which is carried out every 2 years (Kuckartz and Grunenberg, 2002; Kuckartz and Rheingans-Heinze, 2004). Table 2 shows a comparison of environmental attitudes. The items were rated on a scale from 0–4, with 4 meaning total agreement, 0 meaning total disagreement. Again, significant differences on the 0.05 level are marked in grey.

Table 2 Pioneers' attitudes towards the environment

	Pioneers	*Kuckartz and Grunenberg (2002)*[4]	*Significance*	*Kuckartz and Rheingans-Heinze (2004)*[5]	*Significance*
Even today, most people still do not act very environmentally consciously.	2.72	2.84	0.130	2.82	0.183
People like me cannot do much for the environment.	1.31	1.99	0.000	1.86	0.000
There are limits to growth that our industrialised society has already reached or will soon reach.	2.66	2.56	0.361	2.61	0.702
The environment should be protected even if it means loss of jobs.	2.11	1.83	0.004	1.74	0.000
Science and technology will solve many environmental problems without us having to change our lifestyle.	2.08	2.05	0.753	1.9	0.826
Most products of science and technology damage the environment.	1.29	1.79	0.000	1.77	0.000
If we go on like this, we are approaching an environmental catastrophe.	2.38	2.51	0.249	2.58	0.059
It worries me to think about the environmental conditions our children and grandchildren will have to face.	2.34	2.69	0.001	2.78	0.000
When I read newspaper reports or watch TV programmes about environmental problems, I am often outraged and furious.	2.32	2.53	0.022	2.67	0.000
Politicians still do by far too little for the environment.	2.61	2.76	0.108	2.71	0.202
In my opinion, many environmentalists strongly exaggerate the significance of environmental problems.	1.56	2.30	0.000	1.68	0.000

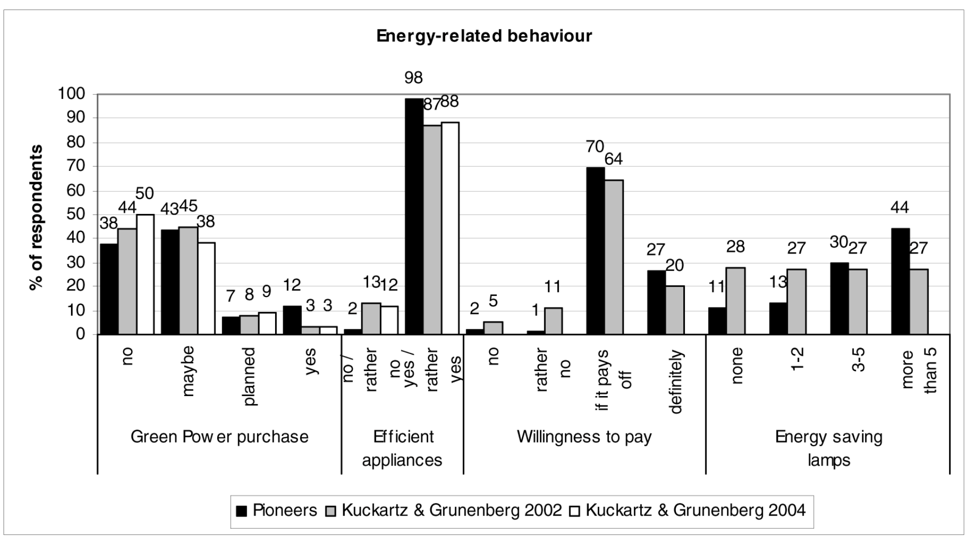
It becomes clear that the pioneers take environmental problems seriously: They strongly reject the notion that environmental problems might be exaggerated, and even prefer the environment over jobs. However, they do not react to the problem emotionally. In the items expressing worry and outrage, they score lower than the general population. The possible reason is that the pioneers have high confidence in their own ability to contribute to a solution. The item 'People like me cannot do much for the environment' is rejected authoritatively. Another difference shows up in the assessment of science and technology: in line with their general trust in technology, pioneers are reluctant in assigning it a role in creating environmental problems.

Contrary to our expectations, they are not especially enthusiastic about the potential of science and technology to solve environmental problems either. In the focus group discussions, however, this idea was expressed clearly. To the group members, the technically advanced was also the environmentally benign. Both notions often melted in the notion of the 'forward looking' or the 'technology of the future'. One likely reason is that focus group members differ from survey participants in as much as only the most committed people volunteered for the discussions. Another possibility is that the whole discussion situation accentuated the topic of environmentally benign technology.

Our picture so far is that the pioneers care about community issues and about the environment, have a positive view of technology and think they can deal competently with new technology and contribute to solving environmental problems. So we might conclude that they themselves take measures to protect the environment, and that technology plays an important role in those measures. We have explored this idea by examining examples of self-reported environmental behaviour and of investment in 'green' technologies, focusing on energy.

Figure 8 shows self-reported environmental behaviour in the energy domain as compared with the *Umweltbewusstsein in Deutschland* surveys. Self-reported behaviour does not exactly mirror real behaviour, but can give an idea about the dimension of a phenomenon. And assuming that the rate of misreporting is about the same in both samples, the comparison is instructive. The actions examined were: purchasing green power, buying efficient household appliances, willingness to pay more for such appliances and number of energy-saving lamps in the household. The pioneers rate better than the general population on any of these items, though the differences do not become statistically significant in the Green Power case. In the other items, significance is at the 0.01 level.

Figure 8 Energy-related behaviour of the pioneers compared with a representative sample[6]



Furthermore, it becomes evident that the pioneers have already invested in various ecologically sound energy-related technologies (Figure 9). This does not only demonstrate their willingness to invest in 'green' technologies but also provides them with some experience and knowledge, lowering the threshold for considering an innovative technology like fuel cells. The role of knowledge is underlined by the fact that many of the pioneers have actively sought out information on different energy- and environment-related issues (Figure 10).

Figure 9 Possession of various (energy-related) environmentally sound technologies

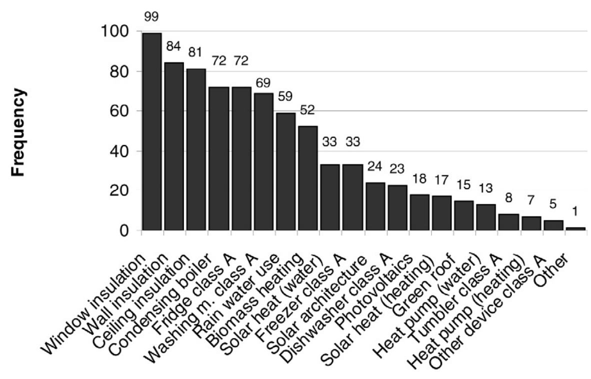
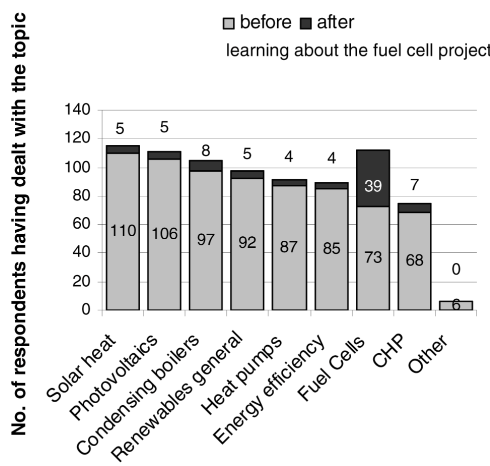


Figure 10 Active information seeking about environmentally sound energy technologies



We have called this phenomenon a 'door opener' effect. It is also underlined by the discussions in the focus groups, where participants report about their experience with wood pellet heating, solar water heaters or ecological building. They express the desire to broaden their portfolio of environmental technologies, as one participant states:

> "My aim is to reorganise the building in terms of optimised use. Better heating and insulation, solar thermal water heating and a fuel cell would be ideal. Later on, one could combine these features with photovoltaics."

Now what have we learned about the pioneers so far? Obviously, they are people with an interest in community affairs and in the environment. They are positive that environmental problems may be solved, particularly with the help of new technology, and they are willing to contribute their share to the solution. Their enthusiasm about technology means that this kind of contribution is not perceived as a sacrifice, but also contributes to personal fulfilment. Focus group participants have emphasised many times that they enjoy monitoring their technical device, be it a solar heat system or photovoltaic panel, to 'tinker' with it and to show it to others.

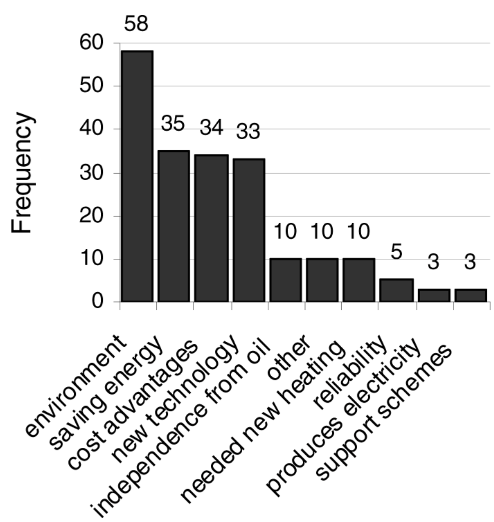
In the next section of the paper, we will look at the actual occasions and reasons given for the interest in the fuel cell system, at the requirements specified and at pioneers' opinion on whether the fuel cell meets those requirements. We will then see whether this fits the picture sketched here.

4.4 Dealing with the fuel cell system: occasion, needs and requirements

Most of the pioneers became interested in the fuel cell project at a practical occasion: 63.2% needed to have their heating system replaced, and 8.3% were constructing a new home. For 4%, their interest was triggered when they learned in the media about the current field test, and 20% reported there had been no specific occasion.

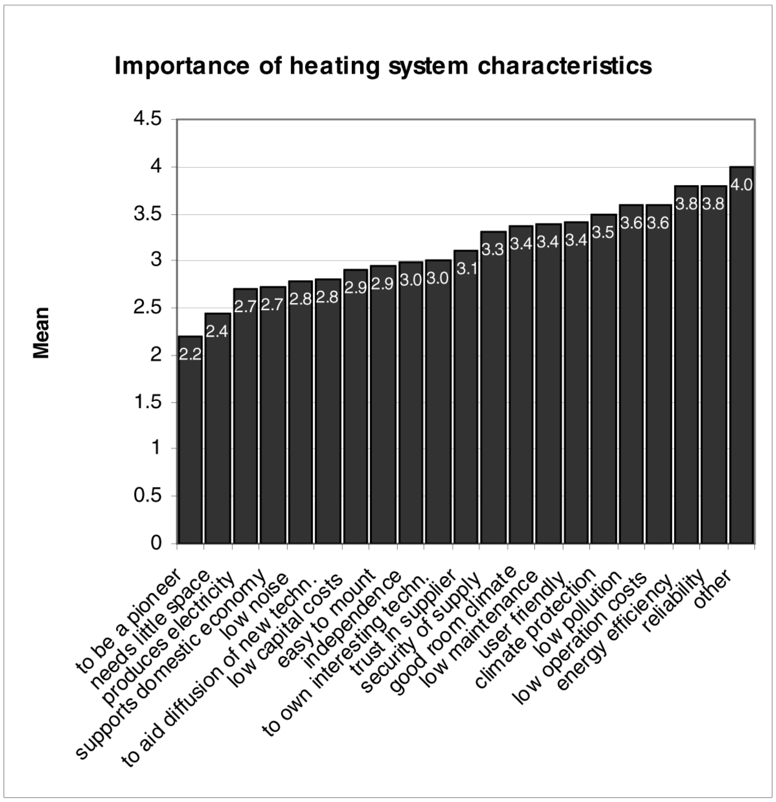
The respondents who had to purchase a new heating system or to replace their old one did consider various alternatives. In fact, most of them have purchased a condensing boiler in the meantime. We asked them in an open question about the reasons to consider the fuel cells; the answers were categorised later. Figure 11 shows the results. We can see that environmental protection (comprising answers like 'environmental protection', 'lowering emissions' or 'protecting resources') is by far the most frequent motive, followed by energy saving (including energy efficiency), cost considerations and interest in the technology. The desire to save energy, by the way, is a hybrid motive; it can stem both from environmental and from economical reasons.

Figure 11 Motives for interest in the fuel cell



So far, the answers fit in the picture of the environmentally concerned citizen. However, there are also contrasting findings. We have asked the pioneers which aspects they find important when thinking about their home energy supply. They were given various aspects which could be rated on a scale from 0 to 4. When confronted with such question, unrelated to fuel cells, the picture changes dramatically. (Figure 12; showing the mean rating of the various items).

Figure 12 Importance of some requirements for home energy systems

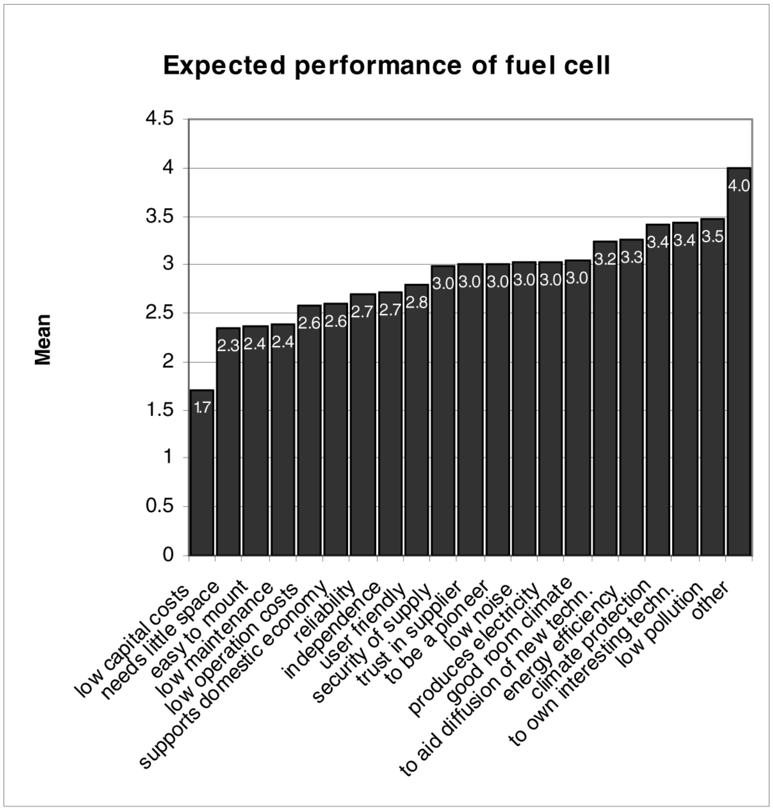


Suddenly, the main concerns become reliability, energy efficiency and low operation costs.[7] The environment comes second, and 'to own an interesting technology' or 'to support the diffusion of new technologies' follow much later.

How can we explain this apparent incoherence? To answer this question, we will first have a look at some more information: the opinion on the fuel cell's performance and some information from the focus group discussions.

After voicing their requirements for home energy supply, the respondents were given the same set of items and asked how well the fuel cell fulfilled them in their opinion. Figure 13 gives the results, again presenting the mean rating of each item, which had been rated on a scale from 0 (does not fulfil it at all) to 4 (fully fulfils it).

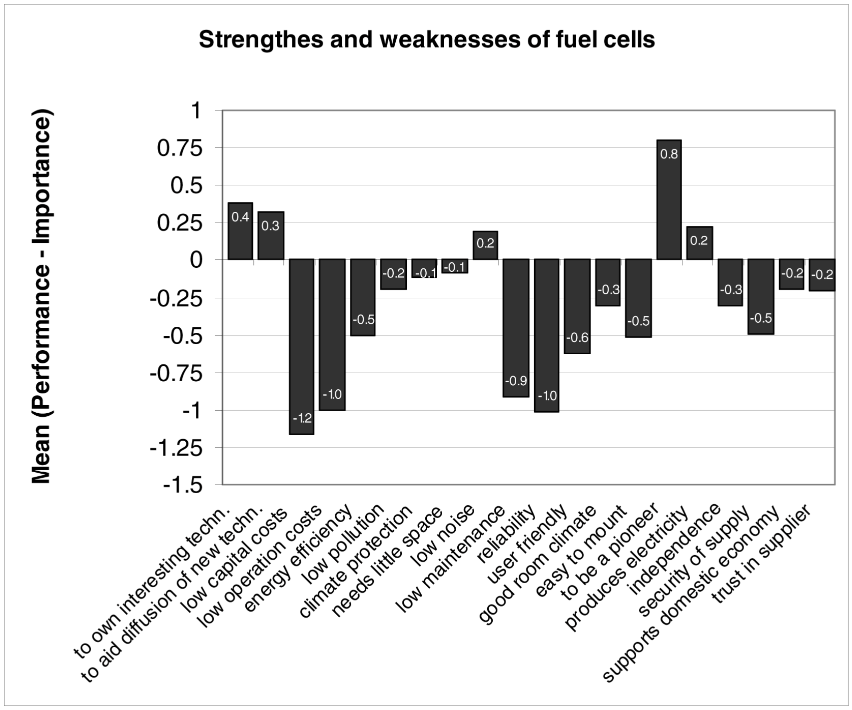
Figure 13 Expected performance of the fuel cell in different areas



According to Figure 13, pioneers see the fuel cell's strength in the domains of environmental benefit and innovative technology. By contrast, they are very sceptical about cost and about 'practical' concerns such as user friendliness, reliability and low maintenance. In addition, many respondents have difficulties to assess how well the fuel cell might perform in these areas. About one third 'don't know' about each of the features 'reliability', 'user friendliness', 'ease of mounting' or 'need of maintenance'. Furthermore, about 25% 'don't know' about operation costs.

The fuel cells' strong points and weaknesses become apparent when we relate the requirements to the expected performance. In Figure 14, we have subtracted the mean importance of each item from its mean rating of performance. Though the two measures are of course not directly comparable, the results give a rough idea of where the main deficits may lie. The negative bars indicate items where performance is rated lower than importance. The longest negative bars can be found in cost items and items that indicate issues of practical, everyday applicability, like low maintenance, user friendliness and reliability. In contrast, on environmental items the fuel cell performs relatively well, and on items indicating the system's innovative potential ('to own an interesting technology', 'to support the diffusion of a new technology' and 'to be a pioneer') it even exceeds the requirements considerably.

Figure 14 Strengths and weaknesses of fuel cells (expected performance in relation to requirements)



This is a realistic picture. In fact, the fuel cell CHP systems promise a good environmental record. However, they still have a long way to go to become operational. At the moment, the prototypes do not function reliably; there are problems with the installation due to the size of the apparatuses; and production and maintenance costs are prohibitive. These problems are also reflected by the focus group participants. They are fascinated by the technology, formulate sweeping visions of a ‘hydrogen economy’ and want to be at the cutting edge of progress. However, they also fear to become technology developers’ ‘guinea pigs’. In exchange for their willingness to contribute, they demand to be protected from economic and technological risk. For this reason, they welcome the contracting agreement that leaves the responsibility for continuous supply in the hands of the energy supplier.

They voice clearly, though, that this arrangement seems only appropriate for the current situation in which fuel cells are not yet fully developed. In general, focus group participants cherish ownership. Should the fuel cell become mature one day, they would prefer to have it in their possession.

In addition to their own reservations, pioneers are aware that risk aversiveness and economical considerations are even stronger in the group of mainstream users. They stress that, in order to win a mass market, fuel cells must become more reliable and, first of all, much cheaper:

> “It is a small, idealistic minority who think like [us]. Most people think differently. The system needs to pay off after 10,12 years –otherwise it won’t succeed.”

> "I'd like to comment on the topic ‚convincing other sections of the population'. In my case, one part of that population was my wife! Women have a more practical perspective. (…) She is sceptical about new developments which pose a certain risk – because you don't want to install a new heating system every few years!"

The last statement points to the importance of the gender issue. Being responsible for the household's functioning and the family's well-being, while usually lacking the technological enthusiasm of their male counterparts, women with a traditional socialisation are definitely harder to reach than men. To them, the new technology suggests possible inconvenience, hassle or even failure, threatening to leave the family in the cold. Although women are in generally more environmentally conscious than men, this applies rather to areas where environmentalism and well-being of the family can be reconciled, like nutrition. In conflict situations, they usually would not let environmental considerations overrun their perceived responsibility for the family.

Against this background, we can interpret the seemingly contradictory results. Like everybody, the pioneers have some very practical, down-to-earth requirements for their heating system. It needs to work reliably, provide some comfort and be economically reasonable. On the other hand, they are well aware that fuel cell CHP is a novel, experimental technology. Because of their keen interest in such technology, and their environmental concern, they want to give it a chance. They are aware of their role as partners in an experiment, pushing the development and diffusion of a novelty. They are willing to contribute as long as they are protected from the biggest risks. However, this does not mean that they will be willing to accept high costs or unreliable quality for the sake of the environment once and for all. They expect that fuel cell development will advance, and that the deficits will be remedied. This is seen as a necessary condition for further market diffusion.

4.5 The pioneers as multipliers

Knowing that the new technology will need some efforts to diffuse, the pioneers are willing to help with that task. In the focus groups, a desire for showing and explaining the technology to others was voiced over and over again. Teachers wanted to show their students; craftsman planned to set up informational events for their colleagues. The pioneers welcomed the opportunity to discuss in focus groups, and they demanded from the energy supplier to 'go public' much more strongly. Some focus group members decided to team up and start drafting a PR campaign. As one member put it: "I look at my solar thermal panel every day. It would be the same with that [fuel cell] system. I'd tell everybody: 'Hey, come on, look, I show you something.'"

In the postal survey, 26% claim to be 'very interested' and 44% to be 'interested' in passing information and showing their fuel cell to others, if they had one. Only 2% each are 'not very interested' or 'not interested at all'. However, they find it important to inform fairly and realistically, naming advantages and disadvantages. They are certainly not only mouthpieces of fuel cell producers or energy companies, and they do not want others to become 'guinea pigs' either.

5 Conclusion

In describing the pioneers, we have been able to confirm most of our hypotheses and answer some questions. Pioneers of fuel cell MicroCHP do indeed come from a well-educated, established middle class population with good income. They are not the urban academic ecologists we found in the photovoltaic case, but rather a more rural and conservative group, but this may be an artefact created by the choice of region. Their education is very often of a technical nature, spurring interest in new technologies. What is striking is their relatively high age and the almost complete absence of women.

As expected, they show a keen technical interest and environmental consciousness. They also combine the two: they hope to be able to solve environmental problems by means of technology. Both concerns converge in the notion of the 'forward-looking' technology. The pioneers trust in their own ability to solve problems – be they of a technical or environmental nature. Therefore, they want to make their own contribution. Many of them possess 'green' energy technologies like solar heat or heat pump, or efficient household appliances. These technologies might serve as a 'door opener'.

Therefore, environmental protection and the desire to be the first in testing a novelty spur their interest in fuel cell MicroCHP. However, like everybody else, the pioneers demand from their home energy system cost-effectiveness, reliability and user friendliness in the long run. In these domains, they spot deficits in fuel cell MicroCHP. They are willing to give the immature technology a chance, but strongly point to the necessity to remedy the deficits in order to reach a mass market.

The pioneers are willing to promote the new technology and function as communicators and multipliers. And, other than predicted by Rogers, they will certainly be able to do so. By no means are they outsiders. Owning a home, a family and a good job or well-earned retirement are what they need to be respected in their community. And they appear to be firmly rooted in that community, doing volunteer work and engaging in political affairs.

What can we conclude from the study for the role of users in the diffusion of energy innovation? It shows that pioneer users can play an important role – first, by their willingness to risk the experiment with a novel, immature technology, test it and give qualified feedback as to the deficits and development needs. Second, by their enthusiasm about sharing their experience and spreading the word by which they can open markets.

It also shows that pioneers are a special group in some, but not in all respects. Technology pioneers are not necessarily lifestyle pioneers. They need not be – and in this case, definitely are not – concerned with sufficiency issues or political ecology. They share the concerns of mainstream users with cost-effectiveness and comfort, but are willing to put them aside for the sake of the experiment. In sharing these concerns, they build an important bridge to the mass market. In willing to put them aside, they are the relevant multipliers and valuable partners that technology developers need to make their products pass the reality test.

For the promoters of sustainable energy, certain recommendations may be followed. First, it would be helpful to not only technically monitor the system's performance but also collect pioneers' experiences and opinions in a more systematic way. This would enable pioneers to help develop the product and adapt it to users' needs. Discussion groups could be established on a regular basis, and formalised feedback tools could be implemented.

Second, the right group should be addressed in the right way. It is helpful to address pioneers in terms of environmental concern and technological enthusiasm. However, to reach a mass market, including women, in the private homeowner sector, more care must be given to insure clients against technical and financial risks. Contracting agreements may be a solution. However, in the German homeowner tradition, such arrangements are not very well known and established. Should companies wish to establish such systems, they will need careful preparation in order to convince clients of their advantages. An alternative could be to address building and housing companies in the tenant sector.

Finally, it is recommendable to make more systematic use of pioneers' willingness to promote the innovation. They may, for example, take part in public relation activities, teaching or information campaigns. In this endeavour, however, firms will need to respect pioneers as partners and take their critical voice as seriously as their compliments.

References

Akrich, M. (1995) 'User representations. Practices, methods, and sociology', in A. Rip, T.J. Misa and A. Schot (Eds), *Managing Technology in Society. The Approach of Constructive Technology Assessment* (pp.167–184). London/New York: Pinter.

ALLBUS (2002) *Allgemeine Bevölkerungsumfrage der Sozialwissenschaften*, cited on 4 September 2006. Available at: http://www.gesis.org/Datenservice/ALLBUS/Daten/all2002.htm

ALLBUS (2004) *Allgemeine Bevölkerungsumfrage der Sozialwissenschaften*, cited on 4 September 2006. Available at: http://www.gesis.org/Datenservice/ALLBUS/Daten/all2004.htm

Beier, G. (1999) 'Kontrollüberzeugungen im Umgang mit Technik', *Report Psychologie*, Vol. 24, pp.684–693.

DENA (Deutsche Energie Agentur) (2003) *Initiative Solarwärme Plus. Marktforschungsergebnisse – Kurzfassung*, Unpublished report.

Genennig, B. and Hoffmann, V.U. (1996) *Sozialwissenschaftliche Begleituntersuchung zum Bund-Länder-1000 Dächer Photovoltaik-Programm*, Umweltinstitut Leipzig, Leipzig.

Greenpeace (1996) *Marktanalyse Photovoltaik. Der deutsche Solarmarkt nach der Greenpeace – 'Cyrus' – Kampagne*, Greenpeace, Hamburg.

Haas, R., Ornetzeder, M., Hametner, K., Wroblewski, A. and Hübner, M. (1999) 'Socio-economic aspects of the Austrian 200 kWp-photovoltaic-rooftop programme', *Solar Energy*, Vol. 66, pp.183–199.

Haas, R., Biermayr, P., Baumann, B., Schriefl, E. and Skopetz, H. (2001) *Erneuerbare Energieträger und Energieverbrauchsverhalte*, Bundesministerium für Verkehr, Innovation und Technologie, Wien.

Hackstock, R., Könighofer, K., Ornetzeder, M. and Schramm, W. (1992) *Übertragbarkeit der Solaranlagen – Selbstbautechnologie. Kurzfassung*, Bundesministerium für Wissenschaft und Forschung, Wien.

Hippel, E.v. (2005) *Democratizing Innovation*. Cambridge/London: MIT Press.

Hocke-Bergler, P. and Stolle, M. (2003) *Anlagenband zum ITAS-Bericht 'Ergebnisse der Bevölkerungsumfragen und der Medienanalyse zum Thema Endlagerung radioaktiver Abfälle'*, cited on 4 September 2006. Available at: http://www.akend.de/projekte/umfrage-main.htm

Hübner, G. and Felser, G. (2001) *Für Solarenergie. Konsumenten- und Umweltpsychologie strategisch anwenden.* Asanger, Heidelberg.

Karsten, A. (1998) 'In der Praxis gewonnene Erfahrungen mit Photovoltaikanlagen in Hamburger Privathaushalten, Unternehmen und öffentlichen Einrichtungen', *Thesis (Diplomarbeit)*, Hamburger Universität für Wirtschaft und Politik, Hamburg.

Katzbeck, G. (1997) 'Der Einfluss von Photovoltaikanlagen auf das Energieverbrauchsverhalten österreichischer Haushalte', *Thesis (Diplomarbeit)*, Technical University of Vienna, Wien.

Kuckartz, U. and Grunenberg, H. (2002) *Umweltbewusstsein in Deutschland 2002. Ergebnisse einer bundesweiten Repräsentativstudie,* Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin, cited on 4 September 2006. Available at: http://www.umweltbewusstsein.de/ub/deutsch/2002/indexub2002.htm

Kuckartz, U. and Rheingans-Heinze, A. (2004) *Umweltbewusstsein in Deutschland 2004. Ergebnisse einer bundesweiten Repräsentativstudie*. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin, cited on 4 September 2006. Available at: http://www.umweltdaten.de/publikationen/fpdf-l/2792.pdf

Ornetzeder, M. and Rohracher, H. (2006) 'User-led innovations and participation processes: lessons from sustainable energy technologies', *Energy Policy*, Vol. 34, pp.138–150.

Pehnt, M. and Fischer, C. (2006) 'Environmental impacts of micro cogeneration', in M. Pehnt, M. Cames, C. Fischer, B. Praetorius, L. Schneider, K. Schumacher and J-P. Voß (Eds), *Micro Cogeneration. Towards Decentralized Energy Systems* (pp.87–116). Berlin/Heidelberg: Springer.

Polzer, G. (2003) *Spaichingen. Von der Sonne verwöhnt*, Lokale Agenda 21 – Arbeitskreis Energie, Spaichingen.

Reif, R. (2000) *Photovoltaik-Siedlung: Aufbau von 23 dachintegrierten PV-Anlagen auf 22 Einfamilienhäusern und dem dazugehörigen Kindergarten im Zuge eines gemeinschaftlichen, räumlich zusammengehörenden Siedlungsbauprojektes. Abschlussbericht*, cited on 4 September 2006. Available at: http://edok01.tib.uni-hannover.de/edoks/e001/313318409l.pdf

Rogers, E.M. (2003) *Diffusion of Innovations* (5th edn). New York: The Free Press.

Rohracher, H., Suschek-Berger, J. and Schwärzler, G. (1997) *Verbreitung von Biomasse-Kleinanlagen. Situationsanalyse und Handlungsempfehlungen*, Bundesministerium für Verkehr, Innovation und Technologie, Wien.

Villiger, A., Wüstenhagen, R. and Meyer, A. (2000) *Jenseits der Öko-Nische*, Birkhäuser, Basel.

Notes

[1]I prefer the term 'pioneers' because 'innovators' evokes the association of the entrepreneur and in fact denotes rather the inventor of some novelty than its first user.

[2]The survey was predominantly conducted by Raphael Sauter, a researcher at SPRU Science and Technology Policy Research, University of Sussex.

[3]A group for comparison is not available, but the test was designed to produce a Gaussian distribution in the general population.

[4]Own calculation from the data.

[5]Own calculation from the published results.

[6]2004 data are not available for the last two items.

[7]We can ignore the category 'Other', because only two respondents named other aspects.

Systematically sustainable provision? The premises and promises of 'joined-up' energy demand management

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Abstract: Energy policy commonly focuses on improving end-user efficiencies and transforming individual behaviour. The need for more 'systematic' policy approaches based on an understanding of complex socio-technical interdependencies between consumers and providers is increasingly acknowledged as a prerequisite for sustainable transitions in the energy sector. The aim of this paper is to examine different system-based approaches, as defined by social and environmental scientists, and consider how they conceptualise socio-technical interdependencies and dynamics of energy systems. Four modes of system-based thinking (human-ecological systems, systems of provision, Large Technical Systems (LTS) and systems of practice) are reviewed. The conceptual and analytical value of each 'systems' approach is subsequently re-examined by drawing on examples of current energy organisation, provision and practice in the UK. This reveals real-life complexities of systems, settings and scales in which energy problems are embedded. Having addressed fundamental questions of what systematic energy management can mean, in theory and practice, further implications for the formulation of more 'joined-up' strategies of demand management are assessed.

Keywords: comfort; consumption; demand; energy systems; social practices; sustainable provision; systematic; transition.

Reference to this paper should be made as follows: Chappells, H. (2008) 'Systematically sustainable provision? The premises and promises of 'joined-up' energy demand management', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.259–275.

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1 Introduction

Energy research and policy is commonly underpinned by the assumption that demand originates from the actions of individual consumers and that the challenge of achieving transition to a more sustainable energy society depends on improving end-user efficiencies. This distinctly individualistic orientation has been challenged by those working in the fields of sociology and science and technology studies who argue that demand for energy and the practices it sustains are dependent on rather more complex socio-technical interdependencies between consumers and providers. It is argued that these interdependencies define the social and institutional context in which different needs evolve and capacities for action are structured (Wilhite et al., 2000). It is only recently, however, that energy policymakers have begun to contemplate the benefits of more systematic and contextual approaches to energy demand management, which embrace more integrative models for connecting consumption and production activities.

Such developments appear promising, but it is still unclear what form system-oriented frameworks for energy analysis and policy might take and on which premises these will be built. The aim of this paper is to examine a variety of system-based theories, and to consider how these might inform contemporary discourses and debates in sustainable energy management and policy. In the course of the analysis undertaken, attention is drawn to a number of distinctive modes of systems thinking that have been applied to the context of infrastructure management. This includes the evaluation of human-ecological systems (Berkes, Colding and Folke, 2003; Berkes and Folke, 2006), systems of provision (Spaargaren, 1997; Van Vliet, Chappells and Shove, 2005), socio-technical systems (Hughes, 1983; Geels, 2004) and systems of practice (Shove, 2003). In respect of each mode of systems thinking, conceptual underpinnings and methods used to identify and understand systemic interactions and dynamics are reviewed. Particular attention is drawn to how demand for energy or the services it provides is understood, both as something systemically constructed and as something to be systematically managed.

Having reviewed different concepts of system organisation, the focus of the paper shifts to examine energy systems in practice. Selected examples from the UK are used to investigate system characteristics and dynamics at different operational scales, and in different organisational settings and contexts. The aim is to compare and review different conceptual models of interaction and interdependency in light of actual evidence of how energy systems work, and how they respond to new pressures. The question of how more systemically sustainable energy demand management might be conceptualised and configured is subsequently reassessed.

2 Emerging systems discourse in energy research and policy

The importance of more strategic or systemic approaches in tackling energy problems has only recently been acknowledged by UK energy researchers and policymakers. The "Energy Review", published by the Policy Innovation Unit (PIU), reports that future energy policy should take into account "the whole energy system" when considering how to meet social, economic and environmental objectives. It is argued that energy strategies need to account for the infrastructure of networks that links supply to demand and the institutional structures that shape, and are shaped by, these technologies (Policy Innovation Unit – PIU, 2002). This implies the need for a considerable shift in the orientation of energy research and policy. Rather than focusing on strategies for the environmental transformation of individual behaviour, what is implied is a more coordinated and integrated approach that links more explicitly consumption and production activities.

In principle this refocusing of attention from individuals to interdependencies along supply chains appears a worthwhile and indeed vital imperative but the significance of more systemically oriented approaches in supporting environmentally sustainable transitions in the energy sector requires further attention to: the meaning of systems being invoked; how systems are understood to be formed and to change; and how demand is seen to be coordinated and constructed. For some, adopting a systemic approach may mean promoting structural improvements in markets or supply chains through coordinating actions aimed at the drivers of demand, including industries, businesses or individual consumers (Vellinga, 2000); for others, it may imply a more fundamental transformation in the systems of provision or practice, such as involving consumers in the co-provision of their own energy supply or re-negotiating the dependencies on existing systems (Shove, 2003; Van Vliet, Chappells and Shove, 2005).

If sustainable transition is to be achieved, policymakers must work with suitably sophisticated understandings of the complex and interactive qualities of energy systems in various material, social, technical and spatial dimensions. In reviewing contemporary system-oriented theories and their relation to current system organisation and practice, this paper aims to: inform debates about the systemic social and institutional structuring of energy demand; and generate further ideas about the multiple points at which the policy might intervene to structure and modify the course of environmentally significant transitions in the energy sector.

3 Modes of system-based thinking

Before examining the different modes of system-based thinking, it is instructive to draw a distinction between the meanings of energy being invoked in these approaches and to reflect briefly on exactly what it is that is being consumed or provided. From a natural or environmental science perspective, what is generally at stake is the flow and circulation of materials or resources between consumers and producers (Vellinga, 2000). Social scientific analyses suggest that it is not energy resources that count when it comes to managing demand but the multitude of services and practices (washing, cooking, cleaning, comfort, etc.) that energy in various forms helps to sustain and reproduce. These distinctions have significant implications when thinking about the types of social, cultural and material interactions and interdependencies that constitute energy systems. Thinking about exactly what is implied by energy consumption is also important in identifying where the opportunities for change lie in the ‘system’ and in defining appropriate demand management responses. If it is energy services that matter rather than resources per se, this opens up the possibility of re-designing the existing technical systems to provide the same level of service using fewer resources. Alternatively, focusing on a specific social practice like comfort brings in an array of actors, such as those involved in defining thermal standards and codes for buildings, not conventionally regarded as key players in shaping energy systems. Keeping these multiple interpretations of what is involved in energy consumption and provision in mind, the following sections review different formulations of systems-thinking from the environmental and social sciences.

In its most basic formulation, an energy system can be represented as a linear and open-ended arrangement where resources and materials flow from the point of production to the point of consumption. As countless studies have shown, this formulation bears little resemblance to the real world of energy organisation (see, for example, Van Vliet, 2003). Besides making no allowance for the re-circulation of resources or waste, the compartmentalisation of consumer and provider at the opposite ends of a supply chain obscures their mutual roles in the structuring of provision and definition of service needs. As such, we need to consider other attempts to define and articulate a systems framework relevant to understanding consumer and provider interactions and dynamics.

As a starting point, it is useful to consider ideas from human and industrial ecology, which provide one prism through which to examine the systemic aspects of energy systems. Founded on the notion that material and resource flows lie behind the problem of unsustainable systems, the focus is on examining the impact of industrial activities, technological development, economic decisions and social aspirations on overall system efficiency.

3.1 Human-ecological systems

From a human ecology perspective human–environment interactions are viewed as a co-evolutionary interrelationship in which the two sides change one another continuously by mutual feedback (Berkes, Colding and Folke, 2003; Berkes and Folke, 2006). Physical environments may place basic physical constraints on the growth and development of human sub-systems, but these in turn actively modify this physical and biological environment, sometimes contributing to the degradation of life-support systems.

For industrial ecologists, human–environment interactions are typically understood in terms of 'closed loop' systems of production and consumption (Frosch and Gallapolous, 1989; Wernick and Ausubel, 1997). In such systems materials do not move linearly from producers to consumers to become waste, but are re-used, re-cycled or re-manufactured to become inputs for new processes. Systems analysis in this case means focusing on material flows and balances and possibilities for materials substitution. By examining local, regional and global flows of materials and energy through industrial processes and products, institutional barriers to change and the potential role of industry in reducing environmental burdens are systematically revealed. Analyses of industrial metabolism can inform the development of life-cycle approaches to energy management, where the aim is to promote the greening of product or supply chains through the systematic transformation of manufacturing processes, markets, technologies and consumer behaviour (Vellinga, 2000).

Even though the issue for industrial ecologists and economists is how to manage the intersection between human and environmental systems, some social theorists argue that the model of human interaction invoked is limited in scope. For a start, the focus has traditionally been on transformations on the supply side and on industrial processes, rather than on revealing the role of domestic consumers in environmental innovation (Spaargaren, 1997). Addressing this deficiency, some industrial ecologists have attempted to incorporate improved models of consumer action into their analyses. Shifting the focus of enquiry from industrial to household metabolism, Noorman and Uitkeramp (1998) offer a diagnosis of household energy and materials consumption. This study offers a basis for improving the efficiency of material and energy flows within households, but is arguably less effective in addressing the 'missing link' between consumption and production (Van Vliet, 2003), the cultural, social and institutional embedding of consumption practices (Otnes, 1988), or in challenging naturalised concepts of need and the basis of current practice (Redclift, 1996; Shove, 2003). Understanding these aspects requires attention to a range of further social scientific endeavours to define system-based frameworks for sustainable provision.

3.2 Systems of provision

Sociologists have also attempted to understand the interrelationships between systems of consumption and provision (Lee, 1993; Spaargaren, 1997; Fine, 2002). A concept used to capture the social interactions between providers and consumers and the dynamics of supply and demand is 'systems of provision' (Fine and Leopold, 1993; Fine, 2002). In analysing the commodity chains through which goods and services are produced, delivered, accessed, used or disposed of, such approaches draw attention to the variety of institutional, organisational and technical regimes that may potentially influence the way demand is constructed and managed.

The appeal of conceptualising energy systems as systems of provision is apparent when considering that energy infrastructures are shared technical networks where consumers are literally plugged into the upstream world of providers (Otnes, 1988; Wilhite et al., 2000). Because production, distribution and household infrastructures are highly interconnected, in a physical sense, the demand and supply management activities of consumers and providers are likely to be highly interdependent (Shove and Chappells, 2001). This means that action in one part of the supply chain influences what happens elsewhere, as has been demonstrated most dramatically in the situations where resources are in short supply. For example, in times of fuel shortage, utilities have often asked consumers to save energy, effectively engaging them as co-managers of the supply system.

In utilising such perspectives, environmental and social scientists have examined how changes in the organisation of energy provision might offer increased opportunities for consumers to become more involved in sustainable transition processes (Spaargaren, 2004; Van Vliet, Chappells and Shove, 2005). The systems framework developed by Spaargaren is further inspired by Gidden's structuration theory (Giddens, 1984), which draws attention to the interaction between humans as knowledgeable agents on one hand and to the institutional rules and resources that frame such knowledge on the other hand (Giddens, 1984). As articulated by Spaargaren, environmentally significant social practices, for example, cooking or cleaning, are simultaneously defined, maintained and reproduced by, and through, the dual interaction of agency and structure.

Taking such arguments further, Van Vliet (2003) argues that the role of consumers in the sustainable transformation of energy systems goes well beyond that of making environmentally efficient purchasing decisions. Consumers are not only end-users but can also act as clients, customers, citizens or co-producers (Van Vliet, 2004). For example, in situations where households produce some of their own electricity, the traditional distinction between consumer and provider is blurred. In representing the consumer as a more active player in the shaping of systems of provision, Van Vliet argues for the dissolution of clear-cut distinctions between the supply and demand sides. Sustainable systems of energy provision are seen to depend not on the actions of consumers or providers but on both together. Households are essentially bound up in much wider socio-collective material systems than individualistic analyses imply (Spaargaren, 1997; Van Vliet, 2003).

Analysing systems of provision also opens up the possibility for multiple conceptualisations of 'the energy system'. Looking at various configurations of energy systems in the UK and the Netherlands, Van Vliet, Chappells and Shove (2005) identify how institutional re-structuring is defining new systems of 'co-provision' operating at multiple scales; for example, households fitting solar panels to roofs or community-level energy grids. Each of these systems appears to represent a unique institutional and social configuration, and to embody different principles of demand or supply management. This multiplicity of scales is seen to open up a range of possibilities for system innovations, some of which may challenge the existing concepts and regimes of energy service – for example, households might accept a more intermittent supply based on the availability of local resources.

Systems of provision methodologies involve the re-constitution of supply chains to understand the systemic intersections between consumers and providers. Their main contribution is to bring the consumer back into view and to acknowledge their multiple roles in shaping sustainable transitions. The work of Van Vliet, Chappells and Shove (2005), in particular, highlights the potential for sustainable innovation and change that works across and through interconnected modes of design, production, access, use and disposal, and operates at a variety of co-existing scales. A third mode of systems thinking addresses the part that technologies play in defining consumer–provider dependencies and structuring the resource intensity of everyday life.

3.3 Socio-technical systems

Technologies clearly affect energy consumption possibilities in different ways. On one level, household technologies act as the mediating devices required to transform energy into useful services, such as cooking, heating or lighting (Shove and Wilhite, 1999). Supply networks are also designed to support certain logics of provision, including large national grids designed to provide near-constant access to energy supplies to small local networks configured to produce energy only intermittently (Medd and Shove, 2005). These technical configurations have a crucial role in shaping the premises on which understandings of demand and possibilities for demand management are founded (Chappells, 2003).

Social scientists working in the field of science and technology studies have attempted to conceptualise social and technical interdependencies in their own system-based analyses (Hughes, 1983; Moss, 2004). The analysis of LTS is especially revealing in respect of energy organisation. In his historical analysis of electricity networks, Hughes (1983) reveals system development to be a long-term process of institution-building and social-structuring. For Hughes, operational principles, such as load management techniques, are the manifestation of efforts by system builders to try and stabilise certain organisational logics. It is in this way that the current organisation of systems and the ability to manage demand can depend on past decisions about the sizing, capacity and responsiveness of interlocking pieces of system hardware. For example, UK electricity systems were traditionally built to meet universal needs and achieve economies of scale. Although these features may have once been crucial in defining the relationships between providers and consumers, recent re-structuring implies a change in the logic of provision from one of facilitating supply to engaging consumers in the management of demand (Guy, Marvin and Moss, 2001). In this context, it is relevant to reflect on how the options for coordinated and strategic demand management are influenced by organisational rules that are embodied in long-standing infrastructural arrangements as well as by current institutional imperatives.

There are clearly important analytical distinctions to be made when thinking about what is part of a socio-technical system or not and how different aspects interact to shape system dynamics. Geels (2004) argues that many analyses of system innovation focus heavily on the processes of production and on the actions of key system builders taking for granted the user environment and the role of institutions in guiding actors' perceptions. For Geels (2004), it is important to incorporate both the supply and demand side in a definition of systems, and crucially to look at the emergent flows of knowledge and distribution networks that link these and which carry and reproduce certain meanings and logics of provision. Geels uses the term socio-technical regime to capture the meta-coordinating role played by product or service standards, scientific practice, policy regimes, markets and socio-cultural norms.

Another important aspect of socio-technical system approaches, or more precisely of system dynamics, concerns the issue of 'path-dependency'; referring to the 'lock-in' effects through which a particular configuration of socio-technological relations limits the possibilities for change (David, 1985; Arthur, 1994; Medd and Shove, 2005). In effect, infrastructures today may embody earlier logics of provision or operational rules that can delay or defer processes of sustainable transition. This is demonstrated by Moss (2004), who describes how technical infrastructures can become a liability through restricting certain options for future development. Path dependency and lock-in imply a certain sort of stability, but socio-technical systems do change. For Geels (2004) and other transition theorists, institutions and infrastructures may act as the carriers of history, but systemic change may take place through multiple interconnected levels of micro niches, meso regimes and macro infrastructures. This relationship between stability and flux is especially significant when thinking about how systemically sustainable transition might be achieved.

3.4 Systems of practice

A final perspective considered here aims to bring social and cultural theories of practice to the fore in thinking about systemic relations. Rather than theorising about supply chain relations or about institutional and infrastructural dependencies, the intention here is to think in terms of emergent arrangements as a whole, and to view systemic arrangements in terms of nested layers of complexity (Shove, 2002, 2003; Urry, 2004). For Urry (2004) and Thrift (1996), complex systems (for example, that of automobility) are hybrid assemblages of humans, machines, buildings, signs and entire cultures. Such systems are 'complex wholes' that cannot easily be reduced to component parts (Urry, 2004). In this context, Urry argues that the challenge of transforming car-based cultures goes beyond the transport system, and requires thinking about the meanings of mobility and about the specific practices or services that require car travel. This argument also has substance when thinking about the meanings of energy and energy systems.

In order to unravel the layers that define and shape complex systems, Shove (2002, 2003) argues for a practice-based analytical approach. Taking the case of laundering, she describes a loosely coupled system of technology, practice and convention. Analysis of laundry practices reveals the interplay of factors and actors that influence the understandings of service at a variety of interconnected levels. This may include personal or collective concepts of cleanliness, social and moral orders, socio-technical regimes or macro institutional or infrastructural structures. By placing the practice of laundering at centre stage, Shove (2002) reveals practices to be constituted by, and constitutive of, a dynamic 'system of systems'. In so doing, she switches the orientation of systems thinking far beyond a focus on supply chains, effectively situating the transformation of demand in an emergent context of attendant regimes and systems that create and sustain everyday practices.

Such an approach might also be used to reveal the systemic arrangements important in shaping energy-intensive practices. Services like 'comfort', for example, are now so embedded in the routines and habits of everyday life (both at the household and institutional level) that it is difficult to trace how and why certain systemic arrangements became normal. Drawing on Shove's approach energy policymakers might usefully ask why it is that people expect to inhabit increasingly uniform indoor environments all year round regardless of the prevailing weather conditions? This form of inquiry brings to light attendant sub-systems of scientific practice, building practice, manufacturing and convention, all of which play a part in the constitution of meanings of comfort and in the systemic transformation of demand (Chappells and Shove, 2005).

3.5 Four modes of systems thinking

As summarised in Table 1, the system-based approaches described above are each used to emphasise certain systemic qualities considered most important in the construction of consumer–provider relations and demand.

Table 1 Typology of system-based approaches

	Organisation of system	*Construction of demand*	*Model of systemic change*
[1] Human-ecological systems	Closed-loop flow of materials and resources	Driven by industries, consumers, markets	Life-cycle approach, improve efficiency of throughput
[2] Systems of provision	Dual configuration of agency and structure	Co-produced by consumers and providers	Greening of socio-collective material systems
[3] Socio-technical systems	Path-dependent socio-technical systems	Institutionally and technically structured, historically grounded	Co-evolution through multiple macro, meso, micro levels
[4] Systems of practice	Practices nested in systems of systems	Socially and culturally embedded expectations of need or service	Redefining expectations and conventions held in emergent sub-systems

These idealised modes of systems thinking further reveal different dimensions that might be incorporated in attempts to define more systematically sustainable energy management possibilities. Insights from industrial ecology help to identify the multiple points at which energy and material flows can be mediated and re-directed to improve the efficiency of technological and ecological systems. Systems of provision approaches, grounded in theories from the sociology of consumption, reveal the variety of attachments between consumers and providers, and how energy services might be re-organised or 'co-provided' at a variety of scales. Meanwhile, notions of systems embedded in a LTS framework introduce ideas of infrastructural entrenchment and tie the historical practices of system builders more concretely to those of current utility practitioners and consumers. Finally, understanding systems as the conglomerations of practices nested together offers a sophisticated interpretation of the interplay of social, cultural and symbolic aspects in shaping resource-intensive habits, routines and norms.

There are clearly innumerable resources to draw on in thinking about socio-technical interdependencies in energy systems and about how sustainable systematic change might be realised. It is also of further interest to reflect on how these models relate to each other. For example, in both [1] and [2] (see Table 1) the analytical focus is on supply chains, but specific points of interest vary significantly. In the former, the objective is to identify proximate causes or driving forces behind demand and to pinpoint possible points for intervention. In the latter, the 're-constitution' of the supply chain is used to reveal the multiple and mutual roles of consumers and providers in creating new modes of service provision.

Approaches [1] and [3] share an interest understanding co-evolutionary change in systems, but underlying models and objectives are quite distinctive. In the former, the concepts of resilience and robustness are used to understand the adaptive capacity of systems to perturbations or shocks (Anderies, Janssen and Ostrom, 2004; Lambin, 2005). What is revealing is that both these concepts focus on how to maintain system functionality and performance. For those studying socio-technical systems, the dynamic interplay between co-existing provider, user and institutional environments are of interest. The questions asked here are how different actors, artefacts and social groups carry and reproduce the system and how new systems might emerge through multiple layers of micro, meso and macro re-structuring. For the former the focus is on maximising the efficiency of throughput in an existing system, for the latter it is questioning the very foundations on which the 'system' is based.

Perhaps, the most striking differences of all emerge between approaches [1] and [4]. The former deals primarily with material or energy flows, while a system of practice framework incorporates cultural and symbolic dimensions of specific practices that constitute energy demand. In turn, the work of industrial ecologists centres on 'closed loop' dynamics, and imagines that the system can be bought back into equilibrium or balance given the appropriate interventions. By contrast, systems of practice are viewed as far from equilibrium systems that are inherently dynamic even in times of apparent stability. Here researchers aim to work with the grain of this real-life fluidity and complexity.

The second part of this paper examines real-life energy system interactions and dynamics in light of the four models discussed. The selected examples are all drawn from contemporary energy systems in the UK; and although not representative of arrangements elsewhere, they offer some illuminating insights into the social and institutional settings in which systemic interactions and dynamics are played out. These exemplary situations offer a basis from which to explore systemic possibilities for tackling the pervasive problem of managing energy demand. They also provide a window on possible points of change or resilience.

4 Exploring energy systems in practice

The UK-based examples considered here are selected to show how contemporary energy systems are organised, how relations between consumers and providers are perceived, how responsibilities for supply and demand are negotiated and how technologies feature in supporting such arrangements. In each case, attention is drawn to the opportunities offered for systematically sustainable energy management, especially as regards the persistently difficult problem of transforming energy demand.

4.1 Supply chain linkages and the scope for system-wide demand management

If ‘joined-up’ energy management is taken to mean the improved coordination of relations between consumption and production (as articulated by systems of provision proponents), we might first reflect on whether current organisational aspects of UK energy systems support this possibility. The specific question considered here is how far the current social or institutional arrangements enhance or diminish the potential for cohesive and coordinated management of energy demand. It is here that interviews with distribution and supply managers in the northwest of England prove especially instructive.

Before the introduction of competition in the UK electricity market, distribution and supply managers often worked for the same regional company. This meant both sets of managers generally had a joint interest in monitoring, coordinating and managing system loads and end-user demand. In the 1990s, new operating rules defined by the regulator meant that the roles of distribution and supply managers within regional electricity companies were increasingly demarcated. In the northwest of England, the sale of Norweb Energi (the supply company) to the Eastern Group in 2000 cut any remaining ties between these organisations. Customers, and by association demand, are now firmly viewed as the responsibility of suppliers, while managing the technical network through which electricity is delivered to these consumers remains the remit of the regionally based distribution business. This demarcation of responsibilities has important implications for the development of coordinated demand management strategies.

The joint role of distribution and supply managers in developing synchronised Demand Side Management (DSM) programmes was considered a relevant option when UK strategies for DSM were first conceived (Office of Electricity Regulation, 1992). In this context, we might reflect on Hughes’ observation that distribution load managers be considered pivotal to the articulation and development of ‘an integrated and cohesive system’, which can enable electricity companies to carefully plan electricity sales, exploit demand diversity and analyse demand patterns (Hughes, 1983). In analysing contemporary arrangements in the UK, there is little evidence to support this positioning of distribution load managers as systemic coordinators and arbitrators of demand within energy systems. Divested of responsibilities on the ‘customer-side’, distribution managers argue that their remit is simply to find ways of meeting rather than managing demand. This process generally involves the incremental reinforcement or expansion of networks to meet the requests of the customers.

For many commodities, this straightforward demarcation of responsibilities might appear quite normal. On the other hand, energy is not a commodity like any other in that provider and consumer groups both operate across what is still a physically interlinked network. This means that decisions by geographically remote supply mangers to promote and install energy-efficient measures in households attached to the northwest supply network have a direct influence on distribution loads. Likewise, it might be expected that standards of service defined by regulators and distribution managers will influence supplier practices and consumer service expectations.

This example illustrates how the re-structuring of institutional arrangements may compromise possibilities for one particular type of strategic demand management, in this context understood as the coordination of network loads. In the situation described, policies supporting the severance of supply chain linkages between consumer and provider interests and new rules concerning the sharing of customer load profiles mean that distribution load managers have little incentive to manage the differentiated demands of users. In this sense, more integrated demand management options – namely those which connect patterns of domestic demand to the effective coordination of supply – may be more difficult to initiate and sustain.

As well as looking at how the re-structuring of institutional dependencies between designated supply and demand managers influences the options for managing demand, it is relevant to consider how localised network arrangements (comprising socio-technical regimes of artefacts, service standards and regulations) support certain strategic management options.

4.2 Socio-technical regimes and the framing of strategic management options

The processes involved in planning and managing loads of different intensity at different network locations and spatial scales vary. These reflect particular configurations of socio-technical arrangements and dynamics.

Focusing again on the example of the northwest electricity network, there are notable 'hotspots' of demand where capacity is already stretched and where it is expected that there will be significant load growth in the future (for example, through increased use of air-conditioning in office blocks). Given the size of the loads involved and diminishing technical capacity, it might be expected that decisions about these problem spots are particularly important in defining future capacity and therefore in determining the scope for system-wide demand management. In reality, the management of hotspots typically involves asking property developers to state how much additional load they expect to require and then figuring out how these extra megawatts might be delivered, either by modifying the existing network or by extending it, for instance, by building new sub-stations. Such approaches are clearly a supply-oriented rather than a systematic response.

In rural areas of northwest England, the situation is somewhat different; here consumers tend to be served by overhead power lines. These technical arrangements make networks especially vulnerable to breakdown and, since homes are quite literally at the end of the network, there is often little scope for the substitution of loads. Regional managers find it difficult to justify investment in these areas, especially given that performance indicators for security of supply, set by the UK electricity regulator, OFGEM, are traditionally based on the number of customers affected when things go wrong. This means that for many UK electricity companies, investments in urban hotspots with high consumer densities are a priority. However, the management of supply and demand remains a political as well as an economic issue, as illustrated by the United Utilities response to the storm damage experienced during the winters of 1998 and 1999. Over these two consecutive Christmas periods, severe storm conditions brought down overhead lines, resulting in widespread power cuts across large parts of Cumbria and the

Lake District. Faced with public and regulatory pressure in response to what was seen as the 'mismanagement' of their network, United Utilities implemented plans for several millions of pounds of investment being pumped into these network cold spots.

Examining these localised load management strategies illustrates how systemic aspects – such as historically configured technical infrastructures, the legacy of public ownership, current regulatory standards and the weight of consumer expectation about security of supply – exert a powerful influence on current decision-making and on the strategies for demand and supply management.

In this and the previous example, the idea of distribution managers as having a role as the systematic coordinators of demand is not really fulfilled. Although these institutional actors have a linking function, as predicted by socio-technical systems analysts like Geels (2004), current strategies appear to be skewed towards the supply side and demand considerations are not fully integrated into the equation. Likewise, user environments are pretty much taken for granted, and consumers are represented as the passive beneficiaries of continuous supply. On the other hand, the investigation of localised problems does show that there are some significant socio-technical conjunctions, around which it may be possible to initiate more widespread systematic transition and uproot conventional orders or regimes.

The organisation of mainstream energy systems offers one set of insights into the meaning and scope of systematic management strategies, which connect consumers to providers, but it also pays to look at other organisational arrangements and the opportunities these offer for the systematically sustainable coordination of demand.

4.3 Niche systems of co-provision and the coordination of demand

There are a number of sustainable housing schemes in the UK, many initiated in the early 1990s, which have tried to achieve some level of autonomy from mainstream energy systems. The Hockerton Housing Project, developed by five households in Nottinghamshire, exemplifies this approach. Instead of relying on mainstream electricity supply, homes are designed to capture solar energy and store this in the form of heat around the building. These passive architectural features are designed to keep householders warm during all but the coldest periods.

The highly localised nature of energy provision means that balances between system capacity and demand are typically tight and unpredictable. Self-providers' ability to heat or light their homes depends on recent weather patterns and hours of sunshine. In light of these structuring conditions, the households involved have developed a distinctive approach to demand management. Rather than building system capacity capable of dealing with extreme loads or reinforcing supply capacity (as is common practice in mainstream grids), households adopt a range of demand management strategies, putting on extra clothes during cooler weather if that is what is needed to 'flatten' peak load and keep the energy supply system in balance. The extent to which localised management strategies of this kind work depends on a variety of factors, including the duration and frequency of supply interruption and the definition of needs that must be met. For example, households at Hockerton have re-negotiated their relationship with mainstream electricity providers in order to secure back-up heating systems for especially cold nights.

This example shows how households (acting as niche network managers) face distinctive challenges in coordinating the spatial and temporal flow of resources and in managing microsystems of supply and demand. In these situations, the distinction between provider and consumer collapses, opening up new opportunities for the coordination of demand and supply and for the 'real time' management of resources and resource-consuming activities.

The experiences of those operating niche or marginal infrastructures help expand the understandings of the relation between consumers and producers, and between supply and demand. The challenges of managing energy between a few households are quite unlike those faced by mainstream utilities. In such situations, the close coupling of supply and demand is likely to be more systemically sustainable than reliance either on supply-side strategies of predict and provide or on demand-side strategies of end-user energy efficiency. In mainstream situations, it appears more difficult to reconcile strategies of institutional demarcation with calls for demand and supply to be systemically managed, through coordinating the activities of a range of co-providers along the supply chain.

4.4 Comfort as a system of systems

In analysing laundry practices, Shove (2002) makes the point that switching the focus of enquiry from resources to practices can reveal new questions about the dynamics of system innovation. It follows that such an approach can address even more fundamental questions about the conceptualisation and constitution of energy systems.

In considering these arguments, it is instructive to consider the case of 'comfort' and specifically the systemic influences shaping practices of comfort-making in the UK today.

Around half of UK domestic energy consumption is now devoted to the tasks of heating and cooling, making sustainable management of comfort a key policy priority. Increased reliance on air-conditioning is further expected to intensify such problems and to require more sustained efforts to manage demand. UK energy policymakers have so far largely taken comfort for granted, viewing their role as one of meeting non-negotiable needs for heating and cooling. Discussions with those who are responsible for specifying and constructing comfort in the UK (including architects, designers, manufacturers and building engineers) reveal a different picture. They suggest that comfort is a highly malleable concept, one that has been defined by the interplay between many different actors and institutions.

Commercial organisations involved in specifying comfort standards for buildings are in part influenced by existing international and global standards, but their decisions are also mediated by a range of local customs and cultures. For example, whether their clients regard it as acceptable to shed the business suit or wear shorts to work. It is these intersecting parameters of established building codes and expectations of 'normal' practice that define acceptable indoor climates and possible forms of adaptation and control. Those involved in designing, specifying and manufacturing heating and cooling technologies also play a role in legitimising and stabilising certain expectations of what it is to be comfortable. Decisions about whether to air-condition or not have implications for how the building occupants understand comfort and for the strategies of coping available to them (e.g. opening a window or adjusting the thermostat). Equally, the practice of routinely heating UK homes to 22°C influences how the design decisions are made and how much indoor climate control there is in practice.

Following the argument made by Shove (2003), discussions with UK comfort-makers reveal the meanings of normal practice to be produced and sustained by the interplay of many factors and actors. The actual achievement of comfort will depend upon the relative influence of different actors and on the theories and models of comfort to which they subscribe. Building designers, manufacturers, regulators and users together shape what is actually built, and hence the conditions to which people become accustomed.

Viewing ‘comfort-making’ as part of a system, or more accurately as a system of systems, has the effect of highlighting important dependencies that are overlooked in analyses with a more supply-oriented interpretation of ‘energy’ systems. As in Shove’s discussion of laundering, there are no obvious system builders in sight or transparently dominant forces in play. It is the continual iteration between those involved in shaping and specifying comfort that is important in shaping the standards of service, in holding the ‘system’ of comfort practice together and ultimately in defining sustainable transition.

5 Energy systems in practice: implications for policy and research

The examples considered here are not necessarily representative of energy system organisation in other regions, localities or countries, but nonetheless offer insights into the contemporary structuring and dynamics of energy demand. They also offer important insights into how systematically sustainable approaches might be generated or precluded in practice, and of the dynamic reconfiguration of possibilities for various forms of coordinated demand management.

Examples of mainstream electricity management in the UK provide little evidence for the more strategic linking of supply and demand activities as envisaged by socio-technical systems theorists. Localised pressure points, like hotspots or cold spots, do reveal the key network conjunctions around which unsustainable logics of provision, such as predict and provide, might be challenged and new operating principles defined, but such opportunities have rarely been pursued. For example, in hotspots where there is little spare capacity, managers might work more closely with property developers to find ways of managing demand, rather than meeting it. In cold spots, consumers might be prepared to act as co-managers of demand or to accept more intermittent supply if they were to be compensated. These sorts of negotiations are a normal part of life for energy self-providers whose work to keep the system in balance is a good reminder of what the alternative forms of systemically sustainable energy co-provision, as predicted by Van Vliet and others, might look like.

Focusing on the organisation of specific practices – such as comfort – brings into view an array of cultural, social and institutional independencies, not always considered when focusing on energy supply chains or infrastructures. This approach reveals that tackling the energy problem means much more than systemically improving efficiency or coordinating loads; it is also a question of transforming the multiple embedded systems of practice that collectively support unsustainable conventions and expectations.

6 Conclusion

The aim of this paper has been to generate debate about the definition of more strategic and structural frameworks that might inform the social research and analysis necessary for the future governance of complex and dynamic energy systems. It has provided an overview of the current status of systems-oriented research on sustainable consumption and transition. Further insights have been gleaned of the theoretical and analytical resources that may be required to cope with the various complexities of systems, settings and scales in which energy problems are embedded.

Thinking more systematically about energy means moving research, policy and practice away from a focus on end-users to consider more fully the range of social and technical actors involved in managing demand. The different theoretical and analytical approaches considered here each offer a particular sort of prism for viewing energy system organisation and processes of social, institutional and environmental change from a variety of scales. What is clear from reviewing these approaches is that what is part of the system (or not) is defined by the concepts and theories of systems analysts. In this sense, there is no ‘energy system’ as such, but only multiple potential configurations of systems allied to different groups of systems analysts and practitioners. Reviewing these systems also prompts reflection on the meanings of energy and exactly what it is that needs to be managed – for example, a multitude of different services, culturally engrained practices, indistinct bundles of resources or differentiated customer loads. This has immediate implications when thinking about how systematic energy policies might be defined, and where the responsibilities for demand management might lie.

In current energy management and policy formulations, it is customary to take for granted certain features of the ‘system’ – for example, a given level of need, a pre-defined comfort level, or existing institutional order – and to seek to accommodate these, if in more sustainable ways. Given the limited success of demand management strategies in tempering energy use, it may well be necessary in future to challenge such conventions and to look more closely at how these accepted social and technical dependencies support certain unsustainable service needs or logics of provision. The system approaches reviewed here each offer an alternative basis on which to re-assess the current formulations of energy management, policy and practice. Further exploration of these conceptual frameworks, and of the current energy systems in practice, is required in order to understand the intimate interdependencies between consumers and providers, and their joint roles in facilitating systematically sustainable energy provision.

Acknowledgements

Interviews with UK electricity and distribution managers were conducted during 2000/2001 as part of the author’s PhD research funded by a postgraduate training award from the UK Economic and Social Research Council. Details of the Hockerton Housing Scheme are based on discussions with one of the initiators of the scheme, undertaken as part of the EU DGXII project ‘Domus: Domestic Consumers and Utility Services’ (1997–2000, award number: ENVCT970467). Evidence of UK systems of comfort-making is derived from interviews with building scientists, designers, architects and manufacturers undertaken as part of the ESRC ‘Future Comforts: reconditioning urban environments’ project (2003–2004).

References

Anderies, J.M., Janssen, M.A. and Ostrom, E. (2004) 'A framework to analyse the robustness of socio-ecological systems from an institutional perspective', *Ecology and Society*, Vol. 9, p.18.

Arthur, B. (1994) *Increasing Returns and Path Dependence in the Economy*. Ann Arbor, MI: University of Michigan Press.

Berkes, F. and Folke, C. (2006) *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*. Cambridge: Cambridge University Press.

Berkes, F., Colding, J. and Folke, C. (2003) *Navigating Social-Ecological Systems*. Cambridge: Cambridge University Press.

Chappells, H. (2003) *Re-conceptualising electricity and water: institutions, infrastructures and the construction of demand*. PhD Thesis, Lancaster University, UK.

Chappells, H. and Shove, E. (2005) 'Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment', *Building Research and Information*, Vol. 33, pp.32–40.

David, P. (1985) 'Clio and the economics of QWERTY', *American Economic Review*, Vol. 75, pp.332–337.

Fine, B. (2002) *The World of Consumption: the Material and Cultural Revisited* (2nd ed.). London: Routledge.

Fine, B. and Leopold, E. (1993) *The World of Consumption*. London: Routledge.

Frosch, R.A. and Gallopoulos, N.E. (1989) 'Strategies for manufacturing', *Scientific American*, Vol. 261, pp.144–152.

Geels, F.W. (2004) 'From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory', *Research Policy*, Vol. 33, pp.897–920.

Giddens, A. (1984) *The Constitution of Society*. Cambridge: Polity Press.

Guy, S., Marvin, S. and Moss, T. (2001) *Urban Infrastructures in Transition: Networks, Buildings, Plans*. London: Earthscan.

Hughes, T.P. (1983) *Networks of Power: Electrification in Western Society, 1880–1930*. London: The John Hopkins University Press.

Lambin, E.F. (2005) 'Conditions for sustainability of human-environment systems: information, motivation, and capacity', *Global Environmental Change*, Vol. 15, pp.177–180.

Lee, M.J. (1993) *Consumer Culture Reborn: the Cultural Politics of Consumption*. London: Routledge.

Medd, W. and Shove, E. (2005) *Shaping Water Practices by Infrastructure*, Traces of Water 3, Background paper workshop 3 of the UKWIR seminar series 'Traces of Water', Available at: http://www.lec.lancs.ac.uk/cswm/dwcworkshops.htm

Moss, T. (2004) 'Institutional restructuring, entrenched infrastructures and the dilemma of over-capacity', in D. Southerton, H. Chappells and B. van Vliet (Eds), *Sustainable Consumption: the Implications of Changing Infrastructures of Provision* (pp.97–112). Cheltenham, UK: Edward Elgar.

Noorman, K.J. and Uiterkamp, T.S. (Eds) (1998) *Green Households? Domestic Consumers, Environment and Sustainability*. London: Earthscan.

Office of Electricity Regulation (1992) *Demand Side Measures: A report to the Office of Electricity Regulation by LE Energy and SRC International*. Office of Electricity Regulation, Birmingham.

Otnes, P. (Ed.) (1988) *The Sociology of Consumption*. Oslo: Solum Forlag.

Policy Innovation Unit (2002) *Energy Review*. London: Cabinet Office.

Redclift, M. (1996) *Wasted: Counting the Costs of Global Consumption*. London: Earthscan.

Shove, E. (2002) 'Sustainability, system innovation and the laundry', in B. Elzen, F. Geels and K. Green (Eds), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*. Cheltenham, UK: Edward Elgar.

Shove, E. (2003) *Comfort, Cleanliness and Convenience: the Social Organization of Normality*. Oxford: Berg.

Shove, E. and Chappells, H. (2001) 'Ordinary consumption and extraordinary relations: utilities and their users', in J. Gronow and A. Warde (Eds), *Ordinary Consumption*. London: Routledge.

Shove, E. and Wilhite, H. (1999) 'Energy policy: what it forgot and what it might yet recognise', Paper presented in the Proceedings of the *European Council for and Energy Efficient Economy (ECEEE) Summer Study*, 31 May–4 June, Mandelieu, France.

Spaargaren, G. (1997) *The Ecological Modernisation of Production and Consumption: Essays in Environmental Sociology*. PhD Thesis, Wageningen University.

Spaargaren, G. (2004) 'Sustainable consumption: a theoretical and environmental policy perspective', in D. Southerton, H. Chappells and B. van Vliet (Eds), *Sustainable Consumption: the Implications of Changing Infrastructures of Provision* (pp.15–31). Cheltenham, UK: Edward Elgar.

Thrift, N. (1996) *Spatial Formations*. London: Sage.

Urry, J. (2004) *The Complexities of the Global*, online paper Department of Sociology, Lancaster University, Available at: http://www.comp.lancs.ac.uk/sociology/papers/urry-complexities-global.pdf

Van Vliet, B. (2003) 'Differentiation and ecological modernization in water and electricity provision and consumption', *Innovation*, Vol. 16, pp.29–49.

Van Vliet, B. (2004) 'Shifting scales of infrastructure provision', in D. Southerton, H. Chappells and B. van Vliet (Eds), *Sustainable Consumption: the Implications of Changing Infrastructures of Provision* (pp.67–80). Cheltenham, UK: Edward Elgar.

Van Vliet, B., Chappells, H. and Shove, E. (2005) *Infrastructures of Consumption: Environmental Innovation in the Utility Industries*. London: Earthscan.

Vellinga, P. (2000) 'Industrial transformation towards sustainability of the energy system', *Integrated Assessment*, Vol. 1, pp.157–163.

Wilhite, H., Shove, E., Lutzenhiser, L. and Kempton, W. (2000) 'After twenty years of "demand side management" (DSM) we know a little about individual behaviour but next to nothing about demand', Paper presented in the *IPCC Meeting on Conceptual Frameworks for Mitigation Assessment from the Perspective of Social Science*, 21–22 March, Karlsruhe, Germany.

Wernick, I.K. and Ausubel, J.H. (1997) *Industrial Ecology: Some Directions for Research*, published by The Program for the Human Environment, The Rockefeller Institute, New York, Available at: http://phe.rockefeller.edu/ie_agenda/

Socio-technical analysis of the introduction of wind power in the Netherlands and Denmark

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Abstract: Why was Denmark more successful in the introduction of wind power than the Netherlands? In this paper, we analyse both development processes. Our analytical framework consists of a combination of the socio-technical systems approach, which points at the importance of the openings that must be present at both the niche level: the regime level and the landscape level, for an innovation to be successful, and the innovation system approach. From this latter approach, we use the insight of functions that an innovation system needs to fulfil to be successful: entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resources mobilisation and support from advocacy coalitions. The socio-technical system viewpoint reveals the importance of explanatory factors outside the wind power innovation system. The function approach points at detailed explanatory factors within the wind power innovation system. We end with a discussion on our analytical framework and policy recommendations.

Keywords: Denmark; functions; innovation system; socio-technical system; the Netherlands; wind power.

Reference to this paper should be made as follows: Kamp, L.M. (2008) 'Socio-technical analysis of the introduction of wind power in the Netherlands and Denmark', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.276–293.

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1 Introduction

After the oil crises in the 1970s, several Western countries started to develop renewable energy technologies in order to replace fossil fuels. The renewable energy source that people had the highest expectations of was wind energy. Two of the countries that were involved in the development of wind energy were the Netherlands and Denmark. Both governments gave active support to this development. Furthermore, both countries have a comparable wind regime. However, the result of the development of wind energy in each country is very different. In the year 2000, Denmark had a flourishing wind turbine industry that produced wind turbines for the world market. Furthermore, at the end of the year 2000 the cumulative installed capacity of wind turbines in Denmark was 2,340 MW and wind turbines produced 15% of the electricity demand. In the Netherlands, the situation was far less rosy. Although 10–15 wind turbine manufacturers were active on the Dutch market at the beginning of the 1980s, in 2000 only one remained. Furthermore, at the end of the year 2000 only 442 MW of wind turbines had been installed in the Netherlands, the target for the year 2000 having been 2,000 MW. Our main research question is therefore:

What are the reasons for this difference in performance?

Often, siting problems[1] in the Netherlands are mentioned as the reason why the Netherlands are lagging behind in the realisation of wind turbine capacity. However, our research shows that the Netherlands were already lagging behind in the 1980s, when the problems were not prominent yet. Therefore, the siting problems cannot be the only explanation. In this paper, we look for other reasons to explain the difference in performance.

2 Analytical framework

A number of socio-technical studies on the introduction of new technologies show that the success of a new technology is not only determined by technical characteristics but also by the social system that develops and implements (or refuses) the new technology. Most recent socio-technical research on the introduction of renewable energy technologies uses one of these two conceptual approaches: the approach of innovation systems and the approach of socio-technical systems.

In the approach of innovation systems, the social system around a technology is called an innovation system (Freeman and Lundvall, 1988; Lundvall, 1988, 1992; Kamp, 2002), a technological system (Carlsson and Stanckiewicz, 1991; Carlsson et al., 2002) or, more specific, a technology-specific innovation system (Negro, Hekkert, and Smits, forthcoming). As the last-mentioned term is most specific, we will use this term, and abbreviate it to TSIS. A TSIS is defined as (Carslsson and Stanckiewicz, 1991): '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'. The system consists of three main elements (Lundvall, 1992; Kamp, 2002): (networks of) actors and organisations; formal, normative and cognitive rules, or, in other words, institutions; learning processes between the actors.

In the approach of socio-technical systems, the social system around a technology is sub-divided into three levels (Rip and Kemp, 1998; Geels, 2005): the socio-technical landscape, or macro level; the socio-technical regime, or meso level; and the niche, or micro level. The socio-technical landscape is the exogenous environment that usually changes slowly. It influences dynamics at the niche and regime level, but cannot be influenced (easily) by those dynamics. Examples are oil resources or the CO_2

concentration in the air. Niches are the places where new technologies emerge. In these niches, the new technologies are shielded from mainstream market selection, either because they are focused on a specific part of the market, e.g. PV solar panels in the aerospace sector, or because they are protected by public subsidies (Schot and Hoogma, 1994; Kemp, Schot and Hoogma, 1998). This kind of protection is necessary, because new technologies generally perform worse in terms of price/performance than technologies that are already on the market. The socio-technical regime is the level of the technology, or technologies, which is/are currently on the market. For the energy system, this would be the current power production system based mainly on fossil fuels. A socio-technical regime consists of three interlinked dimensions (Geels, 2005): a network of actors and social groups; formal, normative and cognitive rules that guide the activities of the actors; material and technical elements. Socio-technical regimes are characterised by path dependence and lock-in into existing technologies, which makes it difficult for new technologies to enter the regime.

How can the insights developed in these two approaches help us to answer our question, why the Danes were more successful in the introduction of wind power than the Dutch? If we look at the terms TSIS and socio-technical system more closely, we see that they can be used in a complementary way. In a TSIS the focus is on the new technology, and therefore on the niche level of the socio-technical system. Therefore, our aim in this paper is to combine both approaches into one analytical framework. Unfortunately, both approaches are still being developed and therefore do not form real theories, but rather conceptual models: terms and relationships between the terms are shown, but not how and why these relationships occur. Therefore, they cannot provide us with a clear-cut answer on what a TSIS or a socio-technical system should look like to enable the introduction of new technologies in a successful way.

However, the approaches provide us with some clues: from the socio-technical system approach, we derive the insight that in order to introduce a new technology successfully, possibilities, or openings, must exist on all three levels (Geels, 2005). Developments at all three levels must link up and reinforce each other (Verbong and Geels, 2007). So, while in the niche a new, potentially well-fitting technology is being developed, developments in the socio-technical landscape must work in favour of the new technology, and developments in the socio-technical regime must create an opening for the new technology to enter the market. Especially, the latter condition is difficult to fulfil because, as mentioned above, socio-technical regimes are characterised by path dependence and lock-in into existing technologies. This is a result of sunk investments, vested interest of actors in the regime and current regulations and cognitive routines of the actors that support the incumbent technologies in the regime (Unruh, 2000, 2002; Jacobsson, Andersson and Bångens, 2002).

In the innovation system approach, recent research is developing the notion of so-called functions of innovation systems: functions an innovation system should fulfil to be able to successfully introduce new technologies (Jacobsson and Johnson, 2000; Edquist, 2001; Jacobsson and Bergek, 2004; Negro, Hekkert and Smits, forthcoming). The idea of functions was first put forward by Jacobsson and Johnson in 2000, and after that further worked out by them and other authors. During this process, some functions were added or added together or renamed. In this paper, we will use the seven functions in a very recent publication of Negro, Hekkert and Smits (forthcoming). These functions are: entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resources mobilisation and support from advocacy coalitions. We will describe each of the functions below.

2.1 Function 1: entrepreneurial activities

This function is a *sine qua non*: entrepreneurs are crucial for a well-functioning innovation system. Their role is to turn the potential of new knowledge, networks and market into concrete business for the new technology. They can be new entrants on the market or incumbent companies that diversify to the new technology.

2.2 Function 2: knowledge development

Another very important function is the generation of knowledge, or learning (Lundvall, 1988, 1992; Kamp, 2002). In the earlier work (Kamp, 2002; Kamp, Smits and Andriesse, 2004), we focused on the role of learning processes within TSIS. We distinguished four kinds of learning processes: learning by searching, learning by doing, learning by using and learning by interacting. Learning by searching, or R&D, takes place at research institutes and research departments in companies. It consists of the systematic and organised search for new knowledge, or the innovative combination of old and new knowledge. Learning by doing takes place in companies, and consists of increasing production skills, which results in an increase in the efficiency of production operations (Rosenberg, 1982). Learning by using takes place during the utilisation of the technology. Learning by using may result in knowledge about the new technology that could not be predicted by scientific knowledge or techniques.

2.3 Function 3: knowledge diffusion

The fourth kind of learning we distinguish is learning by interacting, or knowledge diffusion. This learning process involves the transfer of knowledge between different actors. Particularly in complex innovation processes, firms are hardly ever able to have or develop all the required knowledge and skills in-house. Successful innovation is to a large degree dependent on close and persistent user-producer contacts. Especially, if the required knowledge is tacit and difficult to formalise and communicate more broadly, knowledge diffusion is difficult and has to occur during direct face-to-face contacts. For successful knowledge diffusion, several conditions have to be fulfilled, like mutual interest in the learning process, norms of openness and disclosure and proximity in the broad sense, including geographical closeness, cognitive closeness and a common language and culture (Kamp, 2002, 2004).

2.4 Function 4: guidance of the search

During technology development, it is impossible to explore every possible development path. Since resources are limited, specific paths or foci have to be chosen. An example is a so-called technological guidepost (Sahal, 1981), which is a technological example that has proven to work. Other examples are goals set by government, for example, the renewable energy share in 2050, or user preferences, or standards and regulations, or expectations within the research community (see e.g. Van Lente, 1993).

2.5 Function 5: market formation

Apart from entrepreneurs, a market also has to be present for a technology to become successful. Since it is difficult for new technologies to compete with incumbent ones, it is important to create a protected market space, or niche. As described earlier, this can be done by way of public subsidies.

2.6 Function 6: mobilisation of resources

To support all activities within a TSIS, resources in the form of financial and human capital are needed.

2.7 Function 7: support from advocacy coalitions

Advocacy coalitions are needed to open a space for the new technology within the incumbent regime. This will be difficult because of vested interests, sunk investments, regulations and routines. Advocacy coalitions will have to create legitimacy for the new technology, counteract resistance to change and mobilise resources in the form of investments or public subsidies.

These functions are of course not independent, but interlinked and influencing each other. For instance, the mobilisation of resources will help knowledge development and market formation. The functions may also influence each other in a circular way, creating self-reinforcing virtuous or vicious cycles (Jacobsson et al., 2002).

So, in summary, our analytical framework consists of a combination of the seven functions developed in the TSIS approach and the broader view from the socio-technical system approach, which looks not only at the level of the new technology but also at the incumbent regime and the socio-technical landscape, and at the openings that these two higher levels provide for the new technology. Does this analytical framework provide us with a good enough theoretical basis to explain the difference in performance between the Danish and the Dutch wind power innovation system? In the following two sections, we will describe the Dutch and Danish cases.

3 Wind power in the Netherlands

The Dutch NOW[2] programme, the National Research Programme on Wind Energy, started in 1976. The reason to start this programme was the oil crisis of 1973. Within this programme, subsidies were provided for R&D into the potential of wind energy in the Netherlands and into wind turbine building. The goal of this programme was to develop a significant wind turbine capacity in the Netherlands, consisting of a large number of large wind turbines (BEOP,[3] 1981; Pelser, 1981). As a result of this research programme, two innovation subsystems developed: the large-scale wind power innovation subsystem and the small-scale wind power innovation subsystem. In the large-scale wind power innovation subsystem, the goal was to develop large wind turbines within a short time period. The actors involved were mainly large companies, research institutes like Delft University of Technology and the ECN[4] research institute, electricity production companies and the government. In the small-scale wind power innovation subsystem, wind turbines were developed at a much slower pace, by starting with very small wind turbines and gradually scaling them up. The companies involved were small. Other actors involved were small wind turbine owners like individual farmers or cooperatives, the ECN research institute and the government.

3.1 The large-scale wind power innovation subsystem

In the Dutch large-scale wind power innovation subsystem, the paradigm was from the 1970s directed towards building many large wind turbines in the Netherlands. In this subsystem, a large amount of theoretical knowledge on wind turbines was gained during research projects at the Delft and Eindhoven Universities of Technology and at the ECN research centre. This knowledge was merely based on aerodynamic knowledge from the aerospace industry. Design models for wind turbines were developed, and more applied research was performed into a.o. structural dynamics and aerodynamics of wind turbines. Slowly, it became clear that wind turbines had their own characteristics and that models and theories form the aerospace industry could not be used without significant adjustment. Furthermore, in the late 1970s and the early 1980s the Delft University of Technology performed research into tipvanes. Theoretical research had shown that small vanes on the tips of wind turbine blades could lead to a 60–70% higher energy yield (Van Holten, 1978; BEOP, 1981). Researchers at Delft University of Technology attempted to build tipvanes that would produce this effect in practice. Disappointingly, they did not succeed.

The knowledge gained was applied to only three wind turbine prototypes and two commercial wind turbines. The turbine prototypes that were built were two Vertical-Axis Turbines, or VATs, and one Horizontal-Axis Turbines or HAT. Test results were to prove which turbine type was the best in terms of energy yields and efficiency (Pelser, 1981).[5] In 1981, the companies Stork, Fokker, Holec and Rademakers built a HAT-turbine, the HAT-25. It had a capacity of 300 kW and a rotor diameter of 25 m. As with the VAT prototypes, the main goal of the HAT-25 project was to obtain measurement results and operational experience (Sens, 1981). The prototype was equipped with two blades and a very advanced regulation system. It could be operated with four regulating procedures (Pelser, 1981; Dekker, 2000). In this way, it could be tested which regulating procedure functioned best. Measurement results of the turbine were satisfactory, and Stork decided to develop a commercial turbine on the basis of the HAT-25 prototype. Of this commercial turbine, called the Newecs-25, three were sold to utilities in the Netherlands and Curaçao.

The intended turbine buyers within this subsystem were electricity production companies. The aim was to build large wind power stations, which would deliver electricity to the electricity grid, analogous to other electricity production units, which were also owned by electricity production companies. However, in the design and manufacturing of the wind turbines the aimed buyers were not involved. The design and manufacturing of the wind turbines was very much a science-push process: the turbines were developed by large companies and research institutes, based on scientific knowledge.

The electricity production companies were, although they were the intended buyers, not very enthusiastic about wind energy. They did not take wind turbines very seriously, because of the small amount of electricity they can produce compared with conventional gas-driven power plants or nuclear power plants. The electricity production companies were of the opinion that because of electricity load management issues only a maximum capacity of 650 MWe[6] of wind turbines could be fitted into the electricity grid and not the thousands of MWe that ECN and other research institutes mentioned. Furthermore, they did not see the need for energy source diversification, since the Netherlands have a large supply of natural gas. Some electricity production companies, like that of Zeeland, Schiedam and Curaçao, were willing to try operating a wind turbine. They each bought a Newecs-25 turbine produced by Stork. However, because these turbines were not tested very thoroughly, they had a lot of operational problems (Verbruggen, 2000). These problems were not good for the electricity sector's opinion of wind energy. Stork also built a horizontal-axis turbine with a capacity of 1 MW and a rotor diameter of 45 m, the Newecs-45 (Hensing and Overbeek, 1985). This turbine was meant as an in-between step towards a 3-MW turbine, which had been calculated to be the most cost-effective turbine (Van Holten, 2000).[7] Only one Newecs-45 turbine was sold. Like the Newecs-25, it suffered many operational problems (Verbruggen, 2000). Because only a limited number of turbines were built, only limited knowledge was gained by learning-by-doing and learning-by-using.

In 1982, at the insistence of the Ministry of Economic Affairs, SEP (the Co-operation Electricity Production Companies) became involved in the large-scale wind energy subsystem. SEP agreed to be involved in the development of a pilot wind power station: the Sexbierum wind power station. This time SEP was very much involved in the design and manufacturing of the wind turbines. Holec produced the turbines of the wind power station. The design and building of the wind turbines, however, entailed a number of problems, resulting in a large delay of the project and in even less enthusiasm about wind energy in the electricity sector (Hutting, 2000; Toussaint, 2000; Verbruggen, 2000).

Because of the many problems, the large financial risks and the small home market, the large companies in the large-scale wind power innovation subsystem, Fokker, Stork and Holec, stopped producing wind turbines in the mid-1980s. After the mid-1980s, the aim of the Dutch wind energy policymakers was to make the knowledge developed in the large-scale wind power innovation subsystem applicable to the small turbine manufacturers. In this way, in the eyes of the policymakers, the goal of developing a significant wind turbine capacity in the Netherlands could still be reached (NEOM[8], 1986).

3.2 The small-scale wind power innovation subsystem

In the period 1976–1980, about ten small companies in the Netherlands began to manufacture wind turbines. They became interested in wind turbines because the National Research Programme on Wind Energy had made R&D subsidies into wind energy and wind turbines available. The small companies all had different manufacturing histories, like making steel constructions or polyester yachts and manufacturing farming equipment (Stam, 2000; Dutch manufacturers, a.n.).

In the small-scale wind power innovation subsystem, the knowledge base was, in contrast with the large-scale wind energy innovation subsystem, learning-by-doing. By way of trial-and-error, small wind turbines were built at first. These turbines were gradually improved and scaled up. Because the turbines were sold in the vicinity of the manufacturing companies, problems were observed and solved quickly in interaction with the users, enabling the manufacturer to learn from these problems (Boersma, 2001).

In the beginning, the turbine manufacturers encountered many difficulties in building reliable wind turbines. Therefore, ECN set up a test field in 1981. On this test field, the turbines were tested and the manufacturers received indications on what was to be improved in their turbine (Stam, Beurskens and Dragt, 1983). Because of the danger of distortion of competition, ECN was not allowed to give specific indications on how to improve the wind turbines (Stam, 2000). And from each other the turbine manufacturers received no help at all: they considered each other as competitors and were not willing to share any knowledge on how they built wind turbines (Stam, 2000).

Another problem that the Dutch wind turbine manufacturers encountered was the small size of the domestic market. The Dutch market was and remained small, because in the Netherlands no investment subsidies were available for wind turbine buyers. Therefore, payback times for wind turbines were large (Werkgroep Duurzaam-energieplan, 1984). Furthermore, wind turbine owners received only small buyback tariffs for the electricity they delivered to the grid. These two factors made buying wind turbines financially not very attractive (Blok, 2000; Langenbach, 2000). The main turbine buyers were renewable energy advocates and farmers (CEA,[9] 1993).

Gradually, the wind turbines became better and larger. However, this process went more slowly in the Netherlands than in Denmark. This caused the inability of the Dutch manufacturers to compete with the Danes on the large Californian market.[10] This factor, together with the small size of the Dutch market, caused financial problems for the manufacturers in the mid-1980s.

From the mid-1980s, wind energy policy started to get involved actively in the activities of the small turbine builders. Because the wind turbine producers in the large-scale wind power innovation subsystem had ceased their activities, the small turbine builders were to be responsible for the production of efficient wind turbines that could produce a significant part of the Dutch electricity supply. Therefore, from the mid-1980s onwards, the research institutes and universities of technologies could only receive R&D subsidies if they made their research results applicable for the small turbine builders (NEOM, 1986). Furthermore, investment subsidies were introduced. This increased the Dutch home market, because utilities started to show an interest in buying wind turbines (IEA,[11] 1987). However, siting problems started in this period and seriously impeded market growth.

From then on, it was actively tried to incorporate the results of learning-by-searching, in the design and manufacturing process of the small wind turbine builders. Researchers from research institutes and Stork worked together with small wind turbine builders in improving and scaling up their wind turbines. However, this cooperation was sometimes difficult, since the paradigms and the approaches were completely different (Verbruggen, 2000; Boersma, 2001).

One manufacturer, Lagerweij, had a different approach. He used the knowledge obtained by learning-by-searching by way of personal contacts in Delft and the picking up of their ideas. This resulted in gradual improvements in his small 75 kW/80 kW turbines, for which he used a.o. ideas on flexible components developed at Delft University of Technology (Van Holten, 2000; Boersma, 2001).

The drive towards fast upscaling and the problems involved with incorporated advanced concepts and components in their wind turbines, combined with the small Dutch home market[12] and the competition from the Danes, who offered better products, resulted in severe difficulties for the Dutch manufacturers in the 1990s. In the year 2000, only one Dutch turbine builder, Lagerweij, remained.

4 Wind power in Denmark

In Denmark, as in the Netherlands, as a result of the 1973 oil crisis a development programme for wind energy was set up in the late 1970s. As in the Netherlands, two wind power innovation subsystem developed, a large-scale and a small-scale. In the large-scale subsystem the focus was on the fast development of large wind turbines by large companies, whereas in the small-scale subsystem both the companies involved and the wind turbines produced were much smaller.

4.1 The large-scale wind power innovation subsystem

The main objective in the large-scale wind power innovation subsystem was to determine under what circumstances and to what degree wind energy could make a contribution to the Danish electricity supply systems (IEA, 1985). Since the Danes did not have their own fossil fuel supply, they were eager to develop a new technology that could make them more self-sufficient in their power supply. The programme was called the Wind Power Programme. Within the programme, the research centre Risø and the Technical University of Denmark were to develop the knowledge needed to build large wind turbines. It was envisaged that a consortium of large Danish firms would build large wind turbine parks owned and operated by utilities. The first measurement programme that was carried out was on the Gedser turbine. This wind turbine had been built in the 1950s by the Danish technician Johannes Juul and had proved to work. It had a capacity of 200 kW, a horizontal axis and three blades (Karnøe, 1991). The Danes did not have an aerospace industry, so they could not use knowledge gained in that sector[13].

In 1977, it was decided to build two 630 kW turbines on the basis of the specifications of the Gedser turbine, one with a pitch[14] control system, as the Dutch HAT-25 prototype had, and one with a stall[15] control system, as the Gedser turbine had. These two turbines were called the Nibe turbines (Karnøe, 1991). No Danish company was interested in building the Nibe turbines. Therefore, the turbines were procured on a multi-contract basis. Other actors involved were Risø, the Technical University of Denmark and the SEAS utility, which partly financed the wind turbines (Van Est, 1999). So, unlike in the Netherlands, in Denmark the turbine owners were involved from the beginning. Like with the Dutch large wind turbines, there were many problems with the Nibe turbines, e.g. fatigue problems in the blades and problems with the gear box (IEA, 1985).

In the early 1980s, eight more large wind turbines were built. All these turbines had a pitch control system, because the Nibe turbine with pitch control functioned better than that with stall control (IEA, 1985). Here also the utilities were involved from the beginning. All but one of these eight turbines was built by the company Danish Wind Technology. The Danish Ministry of Energy and the SEAS utility established this company in 1981 (Van Est, 1999).

All wind turbines suffered problems with the blades and the gearboxes (IEA, 1990; Heymann, 1998). Building wind turbines proved to be more expensive and risky than expected. Furthermore, no large Danish company appeared to be interested in building large turbines. In the early 1990s, the Danish state sold its shares in Danish Wind Technology (Karnøe, 1991). By that time, the Danish small-scale wind power innovation subsystem had demonstrated its ability to manufacture reliable well-working wind turbines that were far cheaper than the wind turbines developed by the large-scale wind power innovation subsystem.

4.2 The small-scale wind power innovation subsystem

In Denmark, as in the Netherlands, a small-scale wind power innovation subsystem developed as from the late 1970s, which was relatively independent of the wind energy R&D programme set up by the Danish state. The first wind turbine producers in this subsystem were adherents of the grassroots movement and small entrepreneurs. These actors re-discovered the Gedser wind turbine and started developing wind turbines based on this example.

By 1978, about ten small wind turbine companies had developed. Many of these had previously manufactured agricultural equipment. Their knowledge was based on the manufacturing of machines, and they learned slowly, by way of trial-and-error, how to manufacture and improve wind turbines (Karnøe and Garud, 2001). They obtained their knowledge from the Gedser turbine, from their own trial-and-error experience in the design and production of wind turbines and from the turbine users, either individually or collectively during the so-called Wind Meetings.[16] The turbine companies' design philosophy was to build wind turbines that worked reliably and safely (Karnøe, 1995). They were under pressure to improve their turbines, especially because the performance of their turbines was made public in the magazine, *Naturlig Energi*. The Danish Windmill Owners Association set up this magazine. In the magazine, the performance of the several types of turbines was disclosed. Because they were organised, the users created a strong selection environment for the first Danish turbine builders (Heymann, 1998; Karnøe and Garud, 2001).

All kinds of problems with a.o. rotor speeds, gear boxes, burned out generators, broken yaw systems were handled. Design and construction were based upon trial-and-error and simple rules of thumb (Karnøe, 1995). The manufacturers were used to this way of working and they refrained from taking risks. Gradually, practical and hands-on knowledge about the poorly understood technology accumulated. On the basis of this knowledge, the design rules were gradually improved.

In 1978, a wind energy department was created at the Risø research centre. Because the research centre had only received financing for 3 years, their strategy was to be of immediate service to the wind turbine manufacturers. If the manufacturers could be convinced of the usefulness of the research centre, it could in the future get its financing through orders from the manufacturers (Dannemand Andersen, 1993). Therefore, the goal of the members of the research centre was not to develop the technically best wind turbine but to develop a wind turbine industry. In this way, a tight network between wind turbine producers, owners and the Risø research centre developed within the small-scale wind power innovation subsystem. Because most turbine producers chose to follow the technology guidepost formed by the Gedser turbine, they produced the same turbine type, i.e. a three-bladed stall-regulated wind turbine (Karnøe, 1991). This made the exchange of knowledge very efficient. Therefore, learning-by-interacting went very well within the subsystem.

Another favourable circumstance was the size of the Danish home market. Already in 1979, investment subsidies were introduced (Van Est, 1999). This made buying a wind turbine far more attractive than in the Netherlands. The relatively large home market gave the Danish turbine manufacturers the opportunity to produce a relatively large number of wind turbines and learn by doing during the process. Furthermore, the relatively large user group, which had organised itself in the Windmill Owners Association, was able to act as a strong party during negotiations on buyback tariffs with the utilities.

In the early 1980s, the size of the Danish home market decreased. However, at the same time a very large market arose in California, because large investment subsidies for wind turbine buyers were introduced there (Van Est, 1999). Because the Danes produced relatively good wind turbines and were able to prove this with the statistics in the *Naturlig Energi* Magazine, they were able to capture a large part of the Californian market. In 1985, they sold 2,000 wind turbines to California (Karnøe and Garud, 2001). However, wind turbine demand in California was different from that in Denmark. In California, the buyers wanted larger and more cost-effective wind turbines (Van Est, 1999). This forced the Danes to speed up technology development and to sell turbines that had not yet been thoroughly tested (Karnøe, 1991). This resulted in severe technical problems for the Danish manufacturers.

In 1986, the Californian investment subsidies expired. Exports declined and came to a halt in 1988 (Gipe, 1995). However, the Danish market had started to grow in 1985. In that year, the utilities had signed a 100-MW agreement, which meant that they had to install 100 MW of wind turbines within the next 5 years (Van Est, 1999). This enabled the Danish turbine manufacturers to make a new start. The Wind Turbine Guarantee Company was set up to guarantee the long-term financing of large export projects (Van Est, 1999). With the help of Risø, the Danish manufacturers succeeded in meeting the utilities' demand and building up a strong position on the world market. Siting problems did appear in Denmark as well in the 1990s, but they were less severe than in the Netherlands. Reasons are the lower population density in Denmark and the fact that in Denmark more wind turbines were owned by cooperations of people living near the wind turbines. Therefore, they could also reap the benefits from the wind turbines.

5 Conclusion and discussion

Now let us get back to our research questions: What are the reasons for the difference in performance between the Dutch and the Danish wind power innovation systems? And: does our analytical framework provide us with a good enough theoretical basis to explain the difference in performance between the Danish and the Dutch wind power innovation system?

In this section, we will first analyse to what extent developments at the niche level (the wind power innovation system), the socio-technical regime level (the incumbent power regime based on fossil fuels) and the socio-technical landscape level linked up and reinforced each other in both countries. Secondly, we will look at each of the innovation system functions. After that, we will reflect on the usefulness of the analytical framework for our analysis.

5.1 Socio-technical landscape – regime – niche

In both countries, landscape developments were favourable for the development of wind power. The oil crises in the 1970s made the need for the development of power production technologies that could make the countries more self-sufficient eminent. However, this need was larger in Denmark since it does not own its own fossil fuel supply, whereas the Netherlands owns a large natural gas field. Environmental concerns – ‘acid rain’ in the 1980s and the greenhouse effect in the 1990s continued the legitimacy of the development of renewable power production technologies throughout the period 1973–2000.

With regard to the developments at the regime level, the situation is more different in both countries. In the Netherlands, incumbent regime actors are not very enthusiastic about wind power. The electricity production companies and the utilities did not take wind power very seriously, because of the small amount of electricity wind turbines can produce compared with conventional gas-driven power plants or nuclear power plants. Secondly, they did not see the need for energy source diversification since the Netherlands have a large supply of natural gas. Thirdly, the Dutch electricity production companies were in favour of building replacing fossil-fuel-driven power plants with nuclear power plants instead of with renewable energy like wind power or biomass. Also technical problems existed. Wind turbines did not fit very well into the existing electricity network because of load management and grid connection problems. Furthermore, the decentralised character of wind turbines did not fit into the existing regime either. Utilities favoured centralised electricity production and were not willing to pay good payback tariffs to wind turbine owners.

In Denmark circumstances were more favourable, although similar problems existed concerning grid connection and load management. But because of the lack of a Danish fossil fuel supply, regime actors were more interested in wind turbines than in the Netherlands. Furthermore, the utilities were less dominant actors than in the Netherlands, and therefore they were more willing to negotiate favourable payback tariffs than the Dutch.

5.2 Functions of the innovation systems

Now, let us apply the functional approach we formulated in Section 2 of this paper to the wind power innovation systems in both countries.

5.2.1 Function 1: entrepreneurial activities

In the Dutch case, we see entrepreneurial activities from the early 1980s until the year 2000. However, the number of entrepreneurs involved remains small because of the lack of a large home market (Function 5). The importance of entrepreneurial activities for the innovation system is shown in the large-scale wind power subsystem that collapses in the mid-1980s when the companies involved cease their wind power activities.

In the Danish case, the main problem in the large-scale subsystem is the lack of interest from entrepreneurs. However, in the small-scale subsystem the number of entrepreneurs is relatively large because of the good market conditions.

5.2.2 Function 2: knowledge development

In the Netherlands, the most important form of knowledge development is learning-by-searching, or R&D. This R&D is very successful, shown by the large number of scientific papers and reports and the good international position of Dutch wind energy researchers. However, turning this knowledge into well-functioning wind turbines and good market opportunities proves to be difficult. Learning-by-doing and learning-by-using are of less importance because of the relatively low number of turbines produced.

In Denmark, learning-by-searching, learning-by-doing and learning-by-using are all developed well and complement and reinforce each other via learning-by-interacting (Function3).

5.2.3 Function 3: knowledge diffusion

Our findings on knowledge diffusion, or learning-by-interacting, are very different for both countries. In Denmark, knowledge diffusion developed very well. Knowledge was exchanged between wind turbine owners, producers and researchers on a regular basis, e.g. during the Wind Meetings that the Risø research centre organised every year. Shared goals – making wind power a success by way of gradual upscaling – and closeness in the broad sense – geographically, culturally and because of shared visions and paradigms – made learning-by-interacting successful.

In the Netherlands the situation was different. Within the large-scale subsystem, learning-by-interacting between the researchers and companies went well. They shared goals and paradigms – developing a large number of large, high-tech wind turbines. However, the utilities were not very much involved as a result of their lack of interest and the small number of turbines sold to them, so that they did not participate in the learning process. Within the small-scale subsystem, learning-by-interacting was a problem. Because the number of wind turbines sold was not large, not much knowledge could be exchanged between wind turbine producers and owners. Also knowledge exchange between turbine producers and researchers proved to be problematic. The reason is that they used different approaches and paradigms – science-driven high-tech wind turbine developed as opposed to trial-and-error and learning-by-doing.

5.2.4 Function 4: guidance of the search

Both countries performed well for the function 'guidance of the search', although the guidance was different for both countries. In the Netherlands, the guidance was mainly provided by aerodynamic theories and models from aerospace research, by the goal to develop a large number of large wind turbines at a quick pace and become the world leader in the wind turbine field – just as the Netherlands had always been famous for their traditional windmills.

Denmark lacked its own aerospace research and therefore could not use that as a guidance of the search. However, they had a technological guidepost – the Gedser turbine that was developed by Juul in the 1950s and that had proven to work. Because all Danish wind turbine companies used the Gedser turbine as an example, especially in the 1980s and early 1990s, they followed the same technological path and could therefore learn from each other in an optimal way.

5.2.5 Function 5: market formation

This function has proven to be very important in the wind power case. In the Netherlands, market formation was poor because only R&D subsidies and no market subsidies were available. This small home market had severe impacts on the availability of resources, on the number of entrepreneurs active in the wind power field and on knowledge development (little learning-by-using and learning-by-doing) and knowledge diffusion (as a result of little learning-by-using, little learning-by-interacting between turbine users and producers occurred).

In Denmark, on the other hand, market subsidies were available from the late 1970s. This helped the formation of a relatively large home market at an early stage. Because this market was relatively large, it could organise itself better than the Dutch home market and could therefore negotiate better payback tariffs with the utilities.

5.2.6 Function 6: mobilisation of resources

Interestingly, in the Netherlands far more subsidies were available than in Denmark. However, until 1992 only R&D subsidies were available in the Netherlands. R&D subsidies alone proved to be unable to develop a wind power innovation system. As mentioned earlier (Function5), in Denmark both R&D and market subsidies were available from an early stage. The availability of market subsidies resulted in a relatively large home market, which made more resources available.

In terms of human resources, in the Netherlands a relatively large number of people were involved in wind turbine research, whereas in Denmark a relatively large number of people were involved in wind turbine production.

5.2.7 Function 7: support from advocacy coalitions

Support from advocacy coalitions was larger in Denmark than in the Netherlands. As mentioned earlier, the Danish wind turbine owners were organised better and had a better bargaining positions than the Dutch. Furthermore, the Dutch environmental organisations had an ambiguous role. Although they were in favour of renewable energy, a large number of them opposed wind turbines because of the danger to birds and to the landscape. Thirdly, siting problems were more severe in the Netherlands than in Denmark. This large resistance to the siting of wind turbines seriously hampered Dutch market growth in the 1990s.

5.3 Discussion

In general, we can say that the analytical framework proved to be useful for our analysis. Both the socio-technical system viewpoint – landscape, regime, niche – and the function approach clearly showed us differences between the Dutch and the Danish wind power innovation systems, which help us explain the difference in performance between both countries. The socio-technical system viewpoint reveals the importance of the availability of natural gas in the Netherlands; the Dutch utilities' favour for nuclear power and the dominance of the Dutch utilities in the incumbent electricity regime, which makes the wind turbine owners' negotiation position for buyback tariffs difficult. This viewpoint opens our eyes for explanatory factors outside the wind power innovation system.

The function approach points at detailed explanatory factors within the wind power innovation system – first and foremost, the fact that the Danish market was far larger than the Dutch because of the investment subsidies; secondly, the different ways of knowledge development and diffusion because of different paradigms and different roles of researchers and turbine owners; thirdly, the different ways the search was guided in both countries; and, fourthly, the different sources where the necessary resources came from:

in the Netherlands, mainly R&D subsidies, and in Denmark, mainly market subsidies, the market itself and fixed buyback tariffs.

However, does this analytical framework provide us with the full explanation for the difference in performance between the Netherlands and Denmark? It provides us with a rich picture – it reveals both internal and external factors to the wind power innovation system. However, what it does not take into account are the technological characteristics of the innovation. Wind turbines proved to be a very hard technology to develop, in contrast with the expectations in the 1970s. As Rosenberg writes (Rosenberg, 1982) learning-by-using is especially important in connection with products that consist of complex, interdependent components. When these products are used, especially when they are subject to prolonged stress, the outcome of the interaction of the components cannot be precisely predicted by scientific knowledge or techniques. Therefore, in the case of wind power it is especially important to gain a lot of experience with the technology while it is in use, either as a prototype or as a commercial product. The Danish way of trial-and-error, slow upscaling and early market development proved to be more suited to this specific technology than the Dutch way of high-tech fast upscaling and science-driven technology development. However, for another, more science-driven innovation like nanotechnology, this approach could prove to be more fruitful.

Furthermore, reasoning further, the structure of the innovation system, i.e. the types of actors, organisations and institutions involved, is not in our analytical framework, but appears to be important. As especially for a technology like wind turbines learning-by-using is important, the early involvement of users in the innovation system is important as well. This has clearly been lacking in the Netherlands. Although in our opinion it is in general important to include users in the innovation process at an early stage, so user preference will get articulated at an early stage, this might be more important for technologies that need user experience than for science-driven technologies. For the latter kind of technologies, research institute will be more important.

What can we learn from this research for policymaking? Firstly, all functions of the innovation system (entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resources mobilisation and support from advocacy coalitions) appear to be important for the success of an innovation and need to be addressed. Secondly, both the incumbent regime the new technology has to fit into and the socio-technical landscape need to provide an opening for the new technology. Thirdly, technology specific characteristics are important to take into consideration.

References

BEOP (1981) *Perspectieven voor windenergie, Nationaal Onderzoekprogramma voor Windenergie in Nederland 1976–1981, resultaten en aanbevelingen*, Petten.

Carlsson, B. and Stanckiewicz, R. (1991) 'On the nature, function and composition of technological systems', *Journal of Evolutionary Economics*, Vol. 1, pp.93–118.

Carlsson, B., Jacobsson, S., Holmén, M. and Rickne, A. (2002) 'Innovation systems: analytical and methodological issues', *Research Policy*, Vol. 31, pp.233–245.

CEA (1993) *CEA database on the wind turbines in the Netherlands*, Rotterdam.

Dannemand Andersen, P. (1993) *En analyse af den teknologiske innovation i Dansk vindmølleindustri – Herunder prøvestationen for vindmøllers dobbeltrolle som forskningsinstitution og godkendende myndighed*, Copenhagen: Samfundslitteratur.

Dutch manufacturers (a.n.) *Leaflets from several Dutch manufacturers*.

Edquist, C. (2001) T*he Systems of Innovation Approach and Innovation Policy: an Account of the State of the Art.* DRUID, Ålborg.

Freeman, C. and Lundvall, B.A. (Eds) (1988) *Small Countries Facing the Technology Revolution*. London: Pinter.

Geels, F.W. (2005) *Technological Transitions and System Innovations: a Co-evolutionary and Sociotechnical analysis*. Cheltenham: Edward Elgar.

Gipe, P. (1995) *Wind Energy Comes of Age*. New York: John Wiley & Sons.

Hensing, P.C. and Overbeek, H.H. (1985) 'Nederlands grootste turbine operationeel in Wieringermeer', *Energiespectrum*, December, Vol. 9, pp.254–260.

Heymann, M. (1998) 'Signs of hubris; the shaping of wind technology styles in Germany, Denmark and the United States, 1940–1990', *Technology and Culture*, Vol. 39, pp.641–670.

IEA (1985) *Wind Energy Annual Report 1984*, Paris.

IEA (1987) *Wind Energy Annual Report 1986*, Paris.

IEA (1990) *Wind Energy Annual Report 1989*, Paris.

Jacobsson, S. and Bergek, A. (2004) 'Transforming the energy sector: the evolution of technological systems in renewable energy technology', *Industrial and Corporate Change*, Vol. 13, pp.815–849.

Jacobsson, S. and Johnson, A. (2000) 'The diffusion of renewable energy technology: an analytical framework and key issues for research', *Energy Policy*, Vol. 28, pp.625–640.

Jacobsson, S., Andersson, B.A. and Bångens, L. (2002) 'Transforming the energy system- the evolution of the German technological system for solar cells', *SPRU Electronic Working Paper SeriesNo. 84*.

Kamp, L.M. (2002) *Learning in Wind Turbine Development – a Comparison between the Netherlands and Denmark*, Utrecht: Academic thesis.

Kamp, L.M. (2004) 'Wind turbine development 1973–2000: a critique of the differences in policies between the Netherlands and Denmark', *Wind Engineering*, Vol. 28, pp.341–354.

Kamp, L.M., Smits, R.E.H.M. and Andriesse, C.D. (2004) 'Notions on learning applied to wind turbine development in the Netherlands and Denmark'. *Energy Policy*, Vol. 32, pp.1625–1637.

Karnøe, P. (1991) *Dansk vindmølleindustri: En overraskende international succes; Om innovationer, industriudvikling og teknologipolitik*, Copenhagen: Samfundslitteratur.

Karnøe, P. (1995) 'Institutional interpretations and explanations of differences in American and Danish approaches to innovation', in W.R. Scott and S. Christensen (Eds), *The Institutional Construction of Organizations*. Thousand Oaks,:CA: Sage Publications.

Karnøe, P. and Garud, R. (2001) 'Path creation and dependence in the Danish wind turbine field', in J. Porac and M. Ventresca (Eds), *Social construction of markets and industries*, Oxford: Pergamon Press.

Kemp, R., Schot, J. and Hoogma, R. (1998) 'Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management', *Technology Analysis and Strategic Management*, Vol. 10, pp.175–195.

Kuijs, A.C.M. (1983) 'Ontwikkeling van een megawatt-molen', *Energiespectrum*, October/November, Vol. 7, pp.282–288.

Lundvall, B.A. (1988) 'Innovations as an integrative process – from user–producer interaction to the national system of innovation', in G. Dosi et al. (Eds), *Technical Change and Economic Theory*. London: Pinter Publishers.

Lundvall, B.A. (1992) *National Systems of Innovation – Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Negro, S.O., Hekkert, M.P. and Smits, R.E.H.M. (forthcoming) 'Explaining the failure of the Dutch innovation system for biomass digestion – a functional analysis', *Energy Policy*.

NEOM (1986) *Integraal Programma Windenergie (IPW) 1986–1990*, Utrecht.

Pelser, J. (1981) 'Evaluatie resultaten Nationaal Onderzoekprogramma Windenergie', *Energiespectrum*, June.

Rip, A. and Kemp, R. (1998) 'Technological change', in S. Rayner and E.L. Malone (Eds), *Human Choice and Climate Change*, Vol. 2 (pp.327–399). Columbus, OH: Batelle Press.

Rosenberg, N. (1982) *Inside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press.

Sahal, D. (1981) *Patterns of Innovation*. Reading MA: Addison Wesley.

Schot, J. and Hoogma, R.E. (1994) 'Strategies for shifting technological systems', *Futures*, Vol. 26, pp.1060–1076.

Sens, P.F. (1981) 'Het Nationaal Onderzoekprogramma Windenergie', *Energiespectrum*, July/August, Vol. 5, pp.172–177.

Stam, W.J., Beurskens, H.J.M. and Dragt, J.B. (1983) 'Het ECN windturbinetestveld: algemene ervaringen en werkwijze', *Energiespectrum*, October/November, Vol. 7, pp.274–281.

Unruh, G.C. (2000) 'Understanding carbon lock-in', *Energy Policy*, Vol. 28, pp.817–830.

Unruh, G.C. (2002) 'Escaping carbon lock-in', *Energy Policy*, Vol. 30, pp.317–325.

Van Est, R. (1999) *Winds of Change: a Comparative Study of the Politics of Wind Energy Innovation in California and Denmark*. Utrecht: International Books.

Van Lente, H. (1993) *Promising Technology: the Dynamics of Expectations in Technological Developments*. Twente University: Academic thesis.

Verbong, G. and Geels, F. (2007) 'Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004)', *Energy Policy*, Vol. 35, pp.1025–1037.

Werkgroep Duurzaam Energieplan (1984) *Teruglevertarieven voor windelektriciteit*, Delft.

Interviews

Blok, K. (2000) Personal communication, Professor at Department of Science, Technology and Society at Utrecht University.

Boersma (2001) Personal communication, Lagerwey employee.

Dekker, J.W.M. (2000) Personal communication, employee of ECN, Petten.

Hutting, H. (2000) Personal communication, KEMA, Arnhem.

Langenbach, J. (2000) E-mail communication, wind turbine owner and wind energy advocate.

Stam, W.J. (2000) Personal communication, ECN, Petten.

Toussaint P. (2000) Personal communication, former employee of SEP, Arnhem.

Van Holten, T. (2000) Personal communication, professor at Flight Mechanics & Propulsion Department at Delft University of Technology.

Verbruggen, T. (2000) Personal communication, Stork, Amsterdam.

Notes:

[1]By 'problems of sites' we mean problems that occur if an owner tries to erect (a) wind turbine(s) somewhere. These problems arise because of protests from people living in the vicinity of the wind turbine(s). These protests can result in very long permit procedures or in decisions not to grant permits.

[2]NOW means Nationaal Onderzoeksprogramma Windenergie, or National Research Programme on Wind Energy.

[3]BEOP means Bureau Energie Onderzoek Projecten, or Bureau Energy Research Projects.

[4]ECN means Energieonderzoek Centrum Nederland, or Energy Research Center the Netherlands.

[5]Only two VAT turbines were built in the Netherlands. For more information on these turbines, see Kamp (2002) and Kamp et al. (2004).

[6]MWe means MegaWatts electric, a measure for electric power.

[7]A 3-MW turbine was never built in the Netherlands. Only a pre-design study was performed (Kuijs, 1983). Because of the problems with the Newecs-25 and the Newecs-45, the risk of building a 3-MW turbine was considered too high (IEA, 1987).

[8]NEOM means Nederlandse Energie Onderzoek Maatschappij, or Netherlands Energy Research Institute.

[9]CEA means Centrum Energie Anders, or Center Energy Differently.

[10]This market appeared in the early 1980s, because large investment subsidies were made available for wind turbine buyers in California.

[11]IEA means International Energy Agency.

[12]As from the 1990s, the small size of the Dutch market was also caused by the siting problems.

[13]This in fact turned out to be an advantage for the Danes. Wind turbines were found to have their own characteristics, and therefore models and theories from the aerospace industry could not be used without significant adjustment.

[14]A pitch control system controls the amount of energy a wind turbine draws from the wind by slowly changing the position of the blade, i.e. the angle between the blade and the wind flow.

[15]A stall control system controls the amount of energy a wind turbine draws from the wind by way of the design of the blade. The form of the blade is designed in such a way that the amount of energy drawn from the wind decreases when the wind speed increases.

[16]During the Wind Meetings, knowledge and experience on wind turbines were shared between wind turbine manufacturers, owners and researchers.

Governance in the energy transition: Practice of transition management in the Netherlands

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Abstract: A fundamental transformation of our current energy system in the future is inevitable. To this end, this paper presents a 'fresh' perspective on the Dutch energy field based on transition theory. From this perspective, a number of starting points are suggested for energy transition management in order to influence the speed and direction of the energy transition. In the second part of this paper, these principles are used to reflect upon the way the Dutch Ministry of Economic Affairs is currently applying transition management. As such, this paper itself is part of the ongoing co-production of knowledge between science and policy, that emerged over the past few years in the Netherlands with regard to transition management.

Keywords: complexity; energy transition; governance; sustainable development; transition management.

Reference to this paper should be made as follows: Loorbach, D., van der Brugge, R. and Taanman, M. (2008) 'Governance in the energy transition: Practice of transition management in the Netherlands', *Int. J. Environmental Technology and Management*, Vol. 9, Nos. 2/3, pp.294–315.

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1 Introduction

Looking into the future, increasing scarcity of fossil resources is inevitable (Cavallo, 2004). Consequently, our energy systems will transform fundamentally: towards supply systems that draw from other energy sources. The question is not if, but when and how. What makes this transition hard to deal with is that there is neither consensus about the urgency of the problem nor what the most favourable solutions or strategies are. Governing the energy transition into a sustainable direction is highly complex: because many actors with different perspectives, values and goals are involved so that governance becomes a participatory multi-actor process by definition, and because our current system is deeply embedded into our societal fabric of institutions, infrastructures and economy. This type of complex problem has been labelled as 'persistent' (Dirven, Rotmans and Verkaik, 2002). The persistence of energy-related energy problem is illustrated by the progress made in the international arena (post-Kyoto), which is by far not sufficient to mitigate climate change.

In the Netherlands, the government introduced a new approach to deal with persistent problems. The fourth Dutch National Environmental Plan (VROM, 2001) argued that persistent problems occur in different societal systems: agriculture, mobility, biodiversity and energy. Dealing with these issues at a fundamental level requires long-term and coordinated efforts that take into account economic, socio-cultural as well as ecological and institutional factors. In response, the National Energy Council argued that using *only* current policies is not sufficient (SER, 2001; Energieraad, 2004). Therefore in 2001, the Dutch government adopted the transition management approach (VROM, 2001). The underlying theory – transition theory – provides an integrated analytical approach to conceptualise and understand complex, long-term processes of societal change as multi-causal, multi-actor, multi-level and multi-phase processes, and suggests a new mode of governance, transition management.

In this paper, five energy transition management principles will be derived by integrating the insights from transition theory (Section 2) with the lessons from the historical analysis of the Dutch energy system (Section 3). In Section 4, these five basic principles are defined. Section 5 describes the energy transition management as it was implemented in the Netherlands over the past 5 years. Finally in Section 6, we evaluate this energy transition management process based on the principles presented in Section 4. The paper is a result of participatory action research, literature review and review of policy documents, and aims to contribute to the ongoing debate on how to deal with energy transitions.

2 Transition theory

In this section, we will outline transition theory and how it relates to complex systems science. Transitions refer to large-scale transformations within society or important subsystems, during which the structure of the societal system fundamentally changes. Examples are the demographic transition, transition from industrial to service economies, from extensive to intensive agriculture or from horse-and-carriage to car-mobility (Geels, 2002). A transition is the shift from a relative stable system (dynamic equilibrium) though a period of relatively rapid change during which the system reorganises irreversibly into a new (stable) system again (Rotmans, 1994). Transitions have the following characteristics (Rotmans et al., 2001):

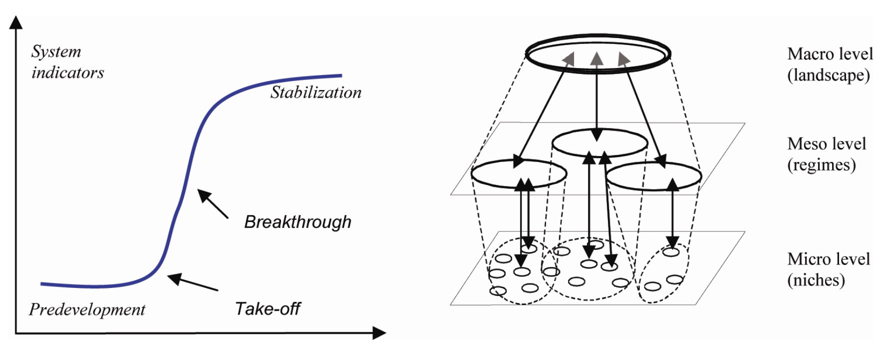
- they concern large-scale technological, economical, ecological, socio-cultural and institutional developments that influence and reinforce each other
- they are long-term processes that take at least one generation
- there are interactions between different scale levels (niche, regime, landscape).

A transition is a complex process with a multitude of driving factors and impacts. It is a process of co-evolving markets, networks, institutions, technologies, policies, individual behaviour and autonomous trends.

Historical analysis of societal transitions (Geels and Kemp, 2000; Verbong, 2000; Van der Brugge, Rotmans and Loorbach, 2005) suggests that transitions go through different stages. Rotmans et al. (2001) argue that the nature and speed of change differs in each of the transition phases (see also Figure 1 for an illustrative representation):

- In the *pre-development* phase the regime remains stable, although the social landscape slowly changes and there is increasing bottom-up innovation.
- In the *take-off* phase the process of change gets under way and the state of the system and its regime begins to shift.
- In the *acceleration* phase structural changes take place visibly way through accumulation of socio-cultural, economic, ecological and institutional changes. During this phase there are collective learning processes, diffusion and institutionalisation processes.
- In the *stabilisation* phase the speed of societal change decreases and a new dynamic equilibrium is reached.

Figure 1 Multi-phase and multi-level models of transition (see online version for colours)



Source: Rip (1998) and Rotmans (2000).

During transitions there is non-linear change as a result of developments and events that reinforce each other. Each development within the whole set has different speed and magnitudes. It is therefore necessary to take into account different scale levels and their interference. The basic multi-level approach that is used here is: focal regime at the meso level, alternatives and innovations at the micro level and long-term trends at the macro level. At the meso-level companies, governments and NGOs are distinguished that together constitute a regime of practices, structure and culture. Rip and Kemp (1998), Geels and Kemp (2000) and Geels (2002) distinguish between the landscape level of trends and autonomous developments (macro), the regime level of institutions and routines (meso) and the micro level at which individuals develop alternatives (innovation).

Transition theory is rooted in theories about the behaviour and dynamics of so-called complex adaptive systems. Complex adaptive systems are systems that consist of adaptive agents which interact. Through their interactions, patterns emerge on higher scale levels that change the conditions to which the individual actors will adapt, which then changes the conditions again and so forth. This dualistic relationship between the individual and system is of key interest to transition theory. Table 1 mentions some of the important properties of complex adaptive systems.

Table 1 Properties of Complex Adaptive Systems (CAS), based on (Prigogine and Stengers, 1984; Holland, 1994; Holling, 1987; Kauffman, 1995). These properties apply to social systems, leading to the conclusions that social systems are complex adaptive systems and that the behaviour of this category of systems may have general features

Properties of Complex Adaptive Systems
Many and divers components and interactions.
Components are organised in a network configuration.
The system is open (exchange of matter, energy and information with external environment).
Non-linearity.
Positive and negative feedback loops (reinforcing and dampening mechanisms).
Nested organisational levels.
Multiple attractors (relative stable but dynamic equilibrium states) co-exist.
Components are able to learn and respond to the environment by changing behaviour (interactions).
Co-evolutionary interaction patterns may lead to irreversible pathways.
Higher level structures spring into being as result of lower level component interaction.

Important insight from complex adaptive systems informing transition theory is the notion of multiple attractors, or multiple stability domains. The idea is that complex adaptive systems remain stable as long as disturbances remain within a certain range, bounded by critical thresholds. After crossing such a threshold, complex adaptive systems transform into a new system. Key assumption behind transition management is that by understanding the dynamics of a societal system as a complex adaptive system, new insights and levers for governance can be found.

We consider the Dutch energy system as complex adaptive. It is an open system that co-evolves with its (societal) environment and related (societal) systems such as mobility, agriculture, spatial and urban development and consumption. It consists of many components: the physical, institutional, economic, mental and technological, which are highly intertwined. It may be conceived of as a nested system: the Dutch energy system in the global context, which in itself consists of different subsystems. During the 20th century, a fossil-based energy regime has emerged and through feedbacks it remains stable. This regime is adaptive since incremental adjustments to external changes are constantly made. The negative feedback processes that control the regimes stability will only be lost when thresholds are crossed, giving rise to positive feedbacks that lead to growth of a new regime. Thresholds in the current energy system include the depletion of the resources and price rates of renewable energy vs. fossil energy rates.

In order to understand the dynamics currently at play in the energy system and the circumstances under which it might reach take-off can be understood from an integrated analysis of the energy-system, and its historic development, by using the multi-level perspective and to indicate the current phase of the energy system.

3 Historical development of the Dutch energy system

The current energy system is the product of an historic transition: from the extensive energy system, based on decentralised energy production, traditional biomass and coal, to the large-scale, efficient energy system based on Natural Gas (NG) and oil. We discern three periods; the period from early 20th century to 1945 as a pre-development phase leading to a take-off, the acceleration phase between 1945 and 1980 and the stabilisation between 1980 and 2000. This long period is chosen to emphasise the time frame of transitions, thus to put transitions to sustainable energy systems in perspective. In the description we focus on the developments in end-use applications, energy use, material infrastructure, institutional framework, fuel mix and political agenda (as also applied to the European electricity system by Verbong, Vleuten and Scheepers, 2002).

3.1 Pre-development (early 20th century – 1945)

Macro trends such as the industrialisation process and widely used steam technology stimulated the use of coal in the Netherlands, like it did elsewhere. Secondary energy carriers, such as electricity and the (coal-based) 'city gas' made their appearance from the 19th century with application on a larger scale from the first decades of the 20th century. They competed for coal as the most dominant energy carrier. Electricity was at first produced locally (with steam engines and later steam turbines), and the retail of centrally produced electricity and gas was a novelty. Both energy carriers were involved in a fierce competition. The first niche-markets were lighting in factories and upper-class homes, but other applications like traction, power, cooking, heating and hot water were actively pursued by the energy companies. Soon, these 'luxuries' became available for the majority of households in areas with an electricity and/or city gas supply. The main drivers were the increasing returns to scale due to the high fixed costs for the production and distribution of these energy carriers. Diversification and increases in the demand lead to more intensive use of existing capacity and a shift towards larger capacity installations. This combined with the emergence of dominant designs and standardisation and incremental innovation caused large cost reductions, the opening up of new markets and so on. This self-reinforcing loop and non-linear dynamics is stronger for electricity, since city gas can be buffered in the grids themselves and in the enormous gasholders that then dominated the skylines. A regional grid that produced the so-called 'distance gas' with central production emerged from around 1925. The diffusion pattern is both bottom-up and top-down; bottom-up through growth of local distribution networks that were connected to one or more higher voltage/pressure transport networks supplied by central power stations or gas factories; top-down when higher voltage/pressure networks stimulated the growth of local distribution grids.

Local governments had the right to issue concessions and thus the energy system at first was organised locally. The large profits, high upfront investments and the economical and social advantages associated with the supply of these energy carriers attracted local governments that started to take over production and distribution from private pioneers. In a later stage, higher level governments took over this role from the municipalities. As electricity distribution grids exceedingly crossed the boundaries of the municipality starting in 1909, the national and provincial governments became increasingly involved. In the resulting power struggle over control of the electricity supply, the joint directors of power plants manifested themselves for the first time. Finally (and in contrast to other European countries), province-owned companies were more or less granted the monopoly in the electricity sector and institutions like the SEP (the cooperating energy producers that are responsible for the planning of power plants and load-balancing). As for city gas, production on a regional scale was coordinated by large (public) enterprises that produced cokes (a coal product): the Dutch State Mines (DSM) and Hoogovens (presently part of Corus), a large producer of steel.

There was no single dominant mode of transport until around 1945, and the linkages to the energy system are therefore diverse. Electric trams, initially coal-fired trains and oil-based cars, competed with each other and with other forms of transport such as bicycles and horse-and-carriages. The competition between these modes of transport sometimes took the form of a simple, cost-driven substitution process, but more often the interaction is much more complex and influenced by market, technological, institutional and infrastructural developments (Geels, 2002). Rail transport had already peaked; and even though cars were relatively rare until 1945, their share in Dutch transport exploded from 1923 onwards.

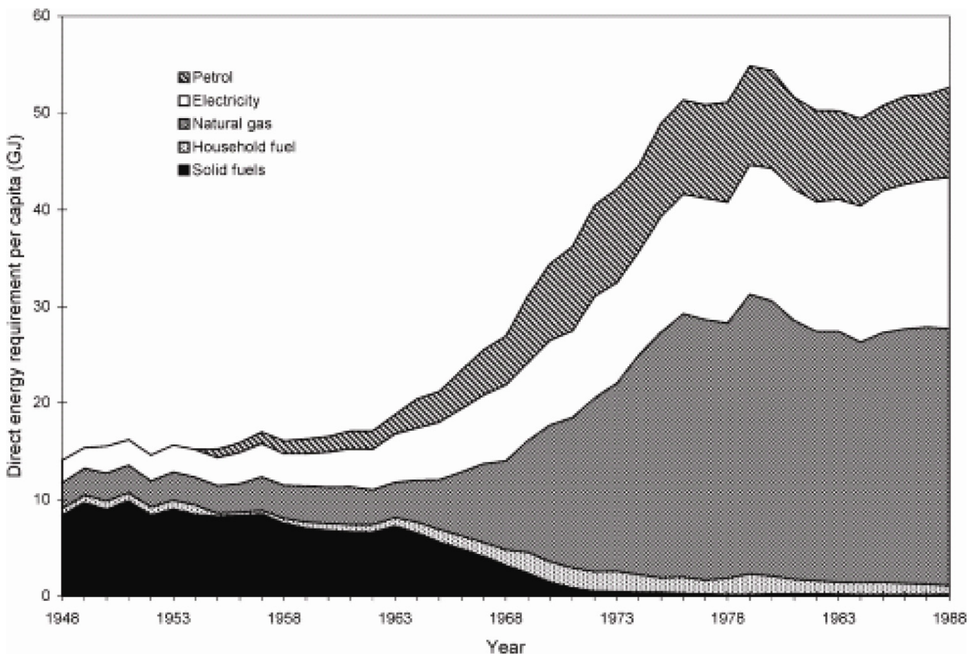
3.2 Take-off and acceleration (1945–1980)

Many of the elements that dominate the next decades and, in part, still dominate the Dutch Energy System were already in place by the end of the 1940s. Energy carriers were produced and organised centrally from fossil fuels and were grid-dependent. There were standards and dominant designs in various markets, and the main rationale was to produce as much energy as possible as cheap as possible. The energy subsystems for stationary applications and transport fuels had a different fuel mix, infrastructure and institutional set-up. Around three quarters of the Dutch households was connected to the city gas distribution grid, 90% to the electricity grid in 1940 and cars account for almost half of the individually travelled distance (CBS, 2005). In hindsight, it seems that most elements that currently constitute the Dutch energy regime were developed before the 1950s and thus before the crucial discovery of the large, Dutch natural gas field in Slochteren in 1953. The gas field in Slochteren produces cheap NG, and in the next decade would contribute significantly to the structural changes in the Dutch primary energy mix (see Figure 2).

Economic and population growth pushed energy use to a relative height around 1980 (Vringer and Blok, 2000). Based on consumption levels, there seems to be a significant shift between relatively low levels of direct energy use to relatively high levels between roughly 1960 and 1980. Underlying are several rapid transitions in subsystems:

- from coal to gas between 1950–1970 (Verbong, 2000)
- from carbon-based to petrol- and synthetic-based chemical industry in the Netherlands between roughly 1940 and 1980 (Schot et al., 2000a)
- from luxury use to mass use of automobiles between 1950s and 1990 (Schot et al., 2000b).

Figure 2 Direct energy requirements (in terms of primary energy) by households per capita



Source: Vringer and Blok (2000).

These changes, however, could not have taken place without the pre-development phase that had created the beneficial 'climate' for change. The DSM became involved in the production and distribution of the NG as they already had experience with city gas; coal mining became less profitable and (at least initially) served the national political interests. Closure of the increasingly unprofitable mines, buy-out of the city gas factories, re-fitting of domestic appliances and installation of a national transport grid were all paid for by the revenues and for a large part coordinated by the national government. The institutional arrangements for production, transport and sales of NG became known as the 'gas house'. The arrangements were influenced by the international context among which are the experiences of NG production by Exxon and tensions about the ownership of oil fields in the Middle East. The Dutch government, DSM, Royal Dutch Oil and Exxon set up a monopoly (run by Gasunie) with a pricing policy that was based on the alternative energy options at that time (as opposed to the cost of NG production). Because NG has considerable end-user benefits, it is more attractive than options like oil and coal. NG revenues accounted for up to 8% of GDP growth between 1950 and 1970, and the domestic energy mix became dominated by NG through its use in power plants, space heating by households and the emergence of new energy-intensive industries (Correlje, Linde and Westerwoudt, 2003). The discovery of the large reservoirs of NG influenced both the transition from coal to oil and the highly anticipated and expected shift from coal to nuclear energy (see for example, Verbong, Berkers and Taanman, 2005).

The sharp increase in car use was not widely anticipated in the Netherlands until WW2 (even though it had already happened abroad), but in the 1950s and 1960s it led to an enormous expansion of road-infrastructure and associated fuel-infrastructure. Institutionally, the energy system for transport was controlled by multinational oil companies like the Dutch/English multinational *Koninklijke Olie*/Shell, which was also involved in NG production and distribution. By 1980, the electricity dispatch was organised by the central power plants, owned by municipalities and provincial governments and working together as a cartel in the SEP (the cooperating energy producers). The Dutch government got more involved with the energy system in this period due to the linkages between industry policy and energy policy (both are a responsibility of the Ministry of Economic affairs), the NG exploitation and macro developments like the oil crisis. Energy policy was used to stimulate energy-intensive sectors like horticulture and regions with less economic activity. This changed the political agenda regarding energy from a focus on controlling the natural monopolies (infrastructures) and enhancing efficient production towards other political goals.

The environmental concerns were increasingly raised during the same period (Meadows, Randers and Behrens, 1972), and a number of environmentally benign technologies were put on the agenda (wind and solar) although in a very early stage of technological development. In the Netherlands, the ever-growing consumption with its associated side effects (waste and emissions) led to increasing public and political pressure and ultimately the first generation of environmental policies and energy-saving measures. These policies were aimed at technological diversification of primary energy sources (favouring a return of coal, but also large investments in wind energy).

3.3 Stabilisation (from 1980)

Despite the shifting political agenda, the Dutch energy system did enter a stabilisation phase. This phase is dominated by incremental development of the energy system. The primary energy sources are NG and oil and energy intensity and – use – stabilise, slowly decoupling economic growth and energy use. Energy efficiency improvements between 1980 and 1996, for example, cut the projected electricity consumption per capita by one third (Vringer and Blok, 2000). Optimisation through, for example, energy efficiency measures and end-of-pipe techniques were for a long time fairly successful, but more fundamental changes towards new energy sources proved to be difficult despite large government efforts. This is illustrated by the very low percentage [ca. 2.4% (CBS, 2005)] of the total energy consumption in the Netherlands, which is considered sustainable in 2005.

However, it seemed that change was already underway. The regime was confronted with changing macro-trends like an increasing environmental awareness, slower economic growth, trends towards privatisation and liberalisation (both in a national and a European context), a lock-in especially regarding infrastructure (sunk costs) and political issues now associated with energy (the debate on nuclear energy, fossil fuel sources, dependency on oil-producing countries, air quality and global warming). Institutionally, gas and electricity markets have been liberalised. In 1989, a new electricity act effectively replaced one from 1938 (Tellegen et al., 1996) and called for decoupling, the formal separation of electricity production and distribution and transportation. Liberalisation of the electricity and gas sector was completed in 2004. Production and transport of electricity and gas is becoming a European instead of a national system. The institutional changes reflect a changing political agenda. The European context, previous unsuccessful attempts to influence parts of the energy system and privatisation/liberalisation and the political problems associated with the present energy system require a change in the role of the national government.

In summary, the transition towards the present, fossil-based intensive energy system was the result of interactions between economic, technological, institutional, behavioural, other developments at different scale levels, and driven by forces outside and inside the system. The transition was in part a result of visions, interests and strategies of different stakeholders, in part driven by laws (e.g. economies of scale) and in part emergent. Relationships between technological options and actors often changed in character, sometimes positive, sometimes negative, sometimes both. Small changes had large impacts (like in the provincial organisation of the electricity sector), and changes that took place as a result of policy happened against the historical background of the energy system (adoption and institutional set-up of NG was very much influenced by previous Dutch experiences with city gas and international experience). At the same time, the dynamics was influenced by the international context. In sum, this illustrates the complexity of such processes of change in which government, planning or market dynamics can only influence part of the process. This obviously raises questions regarding the governance of such processes, which seemingly should include both formal and directed forms of management as well as informal and unplanned ways to create space for autonomous development.

3.4 History repeating?

During the last quarter of a century the Dutch energy regime has changed considerably with regard to institutional and political changes, but end-use applications, consumption levels, infrastructural developments and the fuel mix did not. Based on our analysis, we conclude that the dynamics of the energy system appear to be in a new pre-development stage. Pressure from global warming, depletion of resources (including the domestic NG reserves), political instability due to dependence on fossil fuel producers and attention for sustainable development is growing on average. In addition, there is an increasing sense of urgency due to economic and consumption growth domestically as well as in countries like India and China. Increasing bottom-up pressures at the micro level, such as cheaper renewable technologies, different user and consumption patterns, civil awareness, and debates about decentralised concepts constitute serious alternatives. From this perspective, a new energy transition seems inevitable. The fundamental question is twofold: in which direction should this transition unfold; and are we able to manage such complex transition processes into this desired direction?

4 Governance for the energy transition

In this section, five energy transition management principles are formulated to enhance societal innovations towards sustainable development of the Dutch energy system. The principles are derived from both transition theory and complex systems science, and from the historic analysis, to combine the general with the contextual. Steering in the context of complexity means transforming a complex, adaptive system from one state to another through creating the conditions under which changes can take place. Greater insight into the dynamics of a complex, adaptive system leads to improved insight into the feasibility of influencing and guiding it in a desired direction (see for example: Midgley, 2000). In other words: from applying insights from complex systems science to the energy system management principles can be drawn.[1] In doing this, complexity is no longer to be seen as a problem, but as means to find leverages for steering.

Although past and future transitions are expected to share similar dynamic patterns, namely transformation due to increasing macro pressures and micro alternatives that break through, the context is quite different. Table 2 indicates the main contextual differences with regard to the energy field between the current situation and the situation a hundred years ago.

Table 2 Differences between the historical and desired transition

Main differences between the historical transition and the presently desired transition
Instead of economic growth and technological progress, the driver is now sustainable development. The necessity of this transition is caused by problems that are in part the result of the previous transition (avoiding catastrophe instead of chasing economical, technical and consumer benefits).
The desired transition requires replacement of a much more complex, widespread energy regime crossing local to global scales. Independencies have increased, both within the Dutch energy system and with the Global or European energy system and other Dutch systems (industry, transport, services, etc.).
Larger established infrastructures and stronger interdependence of technologies.
At least on the short term, alternatives offer fewer economical and end-user benefits including increasing returns to scale.
There is a diffuse set of partial problem owners.
The power of national government and central planning has become smaller.
Consumers are accustomed to high levels of consumption and comfort at low costs.

Combining the general conceptual insights from complex systems science with the current Dutch context leads to the energy transition management principles.

4.1 Approach the energy system as a complex adaptive system in its environment

A (conceptual) systems approach enables an integrated analysis of the energy system. It offers a framework to think through interrelations between existing structures, actors, perceived problems and possible solutions. In terms of management, the systems approach implies integrated strategies that take into account formal and informal forms of governance, include a variety of relevant societal domains and involve different strategies at different levels, thereby focusing on influencing and utilising complex system dynamics. Managing the external connections between the Dutch energy system and the global energy system, and between the Dutch energy system and other systems, is essential to influence the transition, for instance, influencing international agreements and finding links with other sectors, such as the housing, transport and mobility sectors, agriculture and water management. The lock-in in of the present energy system is more than a technological lock-in, and the direction of development is shaped by more than innovation or economy alone. A transition requires changes in paradigms, infrastructure, institutions, behaviour, networks, etc. Many of these elements have co-evolved and remain stable through existing positive and negative feedbacks. All these aspects therefore offer opportunities for intervention and neither can be looked at in isolation. Variation, selection and retention play a role and can in part be influenced through stimulating new energy technologies, business models, end-use applications and alternative selection environments (e.g. market niches or semi-protected areas of experimentation) and retention of positive results in new or existing structures (e.g. through schooling, policy plans, new organisations). Central for dealing with transitions is therefore an understanding of the interactions between different levels of scale, in particular niche–regime interactions.

4.2 Deal with uncertainty

Some forms of uncertainty can be reduced by doing research (such as integrated systems analysis); some aspects are inherently uncertain (for instance, what we will learn in the future, or system responses after thresholds crossing) (Van Asselt, 2000). Uncertainties can be learned about actively through intervention in the system, but there will always be surprises. This implies that objectives of governance should be adaptable and adjusted when needed. The complexity of highly dynamic systems is at odds with formulating rigid objectives, blueprints or selecting the 'right' solution. Experts have often been wrong in predicting winning options and major societal trends. Yet this element has been important in the Dutch context, which changed its industry policy in the 1970s from the 'backing losers' philosophy (giving state support to ill-performing large industrial companies) towards picking winners (AWT, 2003).

4.3 Approach the transition as a multi-actor problem-solving process

Transitions and the issue of sustainability are inherently social issues, and therefore governance strategies should involve a wide range of actors. Planned or unplanned change results from the interaction between actors. The transition process thus has an emergent character, both with regard to how a transition issue is formulated in society as well as to what direction is desired. Governance strategies in this context should include structuring and coordinating activities as well as allowing for and creating room for spontaneous and surprising activities. Government should play an active role in this process as a facilitating party, but still as one party among many (Eising and Kohler-Koch, 1999).

4.4 Stimulate new combinations

New combinations of knowledge (e.g. multi-disciplinary knowledge), stakeholders, technologies, policy instruments, etc., might trigger innovation and set of new dynamics. Promoting and maintaining a large variety in system options, and selection environments form a hedging policy to deal with uncertainty. Diversification has been a central theme in energy policy for the past few decades, albeit often expressed in pure technological terms (Verbong, Berkers and Taanman, 2005).

4.5 Be reflexive in the management approach

Every intervention is based upon an incomplete model of the world. Each intervention will also produce unintended side effects and adverse boomerang effects, which can partially be anticipated and partially need to be responded to. A second level of reflexivity lies in the problem-solving process itself. As present issues result in part from past and present management and policies, the assumptions behind management and policies should also be scrutinised (Voss and Kemp, 2005). Governance should therefore include activities and strategies that reflect upon and draw conclusions from the activities and lessons learned.

4.6 Governance framework

In order to translate the above-mentioned management principles into an operational approach, Loorbach and Rotmans (2006) and Loorbach (2007) developed a recursive multi-level framework for transition management. It distinguishes:

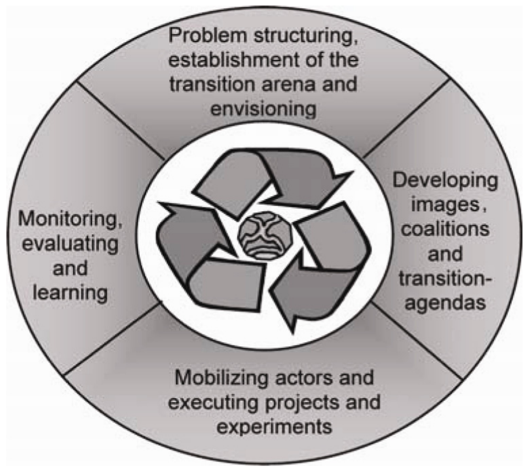
- *A strategic level*: processes of vision development, strategic discussions and long-term goal formulation. Most important at this level are the activities that give direction to social and cultural developments through leadership capacity, long-term orientation and top-down decision-making.
- *A tactical level*: processes of agenda-building, negotiating, networking, coalition building, etc. At this level the regime-structures of a societal system are re-defined through the design of totally new structures envisaged to facilitate a sustainable system, often through co-evolution between actors' interests, agendas and strategies.
- *An operational level*: processes of experimenting, project building, implementation, new practices, etc.

The transition management framework further distinguishes four activity clusters captured in a cyclical model (Figure 3):

- *Problem structuring and envisioning*: identify innovative pioneers and trendsetters, define problems and formulate inspiring alternative visions and images at system level.
- *Agenda building and networking*: representatives, actors and networks negotiate, exchange and co-produce regulations, strategies and intermediate goals (transition images and paths) at sector and subsystem level.
- *Experimenting and diffusing*: entrepreneurs, project managers and (government) officials implement and execute day-to-day operations and actions.
- *Monitoring, evaluating and adapting*: cross-cutting processes that occur at all levels and throughout all phases and designed to raise reflexivity and learning.

This transition management framework enables context specific implementation of the transition management approach based on evolving analysis of the state of a societal system. The analysis of the energy transition (section 3) for example shows that there is a growing concern about sustainability issues and the need for change, while not much debate is ongoing about the implications of a fundamental transition in terms of restructuring economies, consumption and production. In terms of strategic transition management, this would imply creating space for innovative ideas and thinkers and facilitating the development of sustainability visions and images that challenge current ways of thinking and acting by establishing transition arenas (Loorbach, 2007). In the next section we will illustrate practically how energy transition management was developed and implemented in the Netherlands and reflect upon the effects hereof.

Figure 3 Activity clusters in transition management



Source: Loorbach and Rotmans (2006).

5 Energy transition management; a new direction in Dutch Energy policy

In this section, we describe how the transition management approach was implemented the ministry of Economic Affairs (EZ see also: www.energytransition.nl). The Energy Transition management process (ET) started with a scenario report from the working group *'long-term vision for the energy supply-system'.* This report, 'Energy and Society in 2050' (EZ, 2000), linked economic growth and industrial development to energy consumption in terms of yield and supply of (alternative) energy resources. The report identified four possible future worlds. In each of these 'worlds' (the scenario's 'Global solidarity', 'Global markets', 'Regional networks' and 'Regional isolation'), energy demand was analysed. Based on the different scenarios, three sustainability criteria were defined: security of supply, economic efficiency, minimal environmental and social impact (EZ, 2000). Only four alternatives (biomass, NG, energy efficiency and wind energy) proved to be robust across worlds.

Hence, the following four main routes (transition paths) were identified (see Figure 4):

1 New (efficient and green) gas.

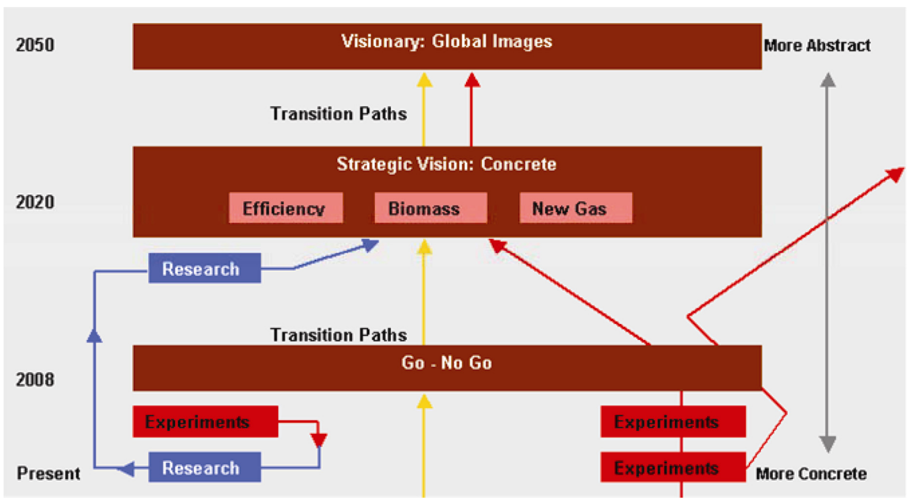
2 Modernisation of energy chains (efficient energy and material use throughout production use chains).

3 Biomass International (for products, materials and energy).

4 Sustainable Rijnmond (an industrialised and urbanised region in the Netherlands).

After a successful preparatory phase, the ministry decided to continue the approach and funded different sub-projects. For each transition theme, platforms (transition arenas) were set up to enable and facilitate discussions within the framework of the overall ambition and the context set by the scenario-study. Stakeholders involved in the platforms were predominantly organisations from business and science that were explicitly active in the areas of interest. They were not so much selected based on (individual) competences, democratic representation or their specific roles within networks, but rather on their possible contribution to development of new technologies or markets. The selection was done by the chairs of the platforms (who were selected by EZ because of their networks and experience in the platform's theme), often from their own network.

Figure 4 General overview of the energy transition process (see online version for colours)



Source: EZ (2003).

The platforms were given the explicit task to develop shared visions, transition paths and transition experiments as concrete as possible. Within the context of these thematic visions, paths were further refined by the transition teams 'new gas', 'biomass international', 'sustainable Rijnmond' and 'modernising energy chains'. Most platforms then started to develop thematic visions, some quantitative [Biomass: 'green resources have replaced 30% of the resources used for our energy supply in 2030. This implies: 60% of total fuels, 25% of resources in the chemical sector, 25% of resources for electricity and 17% of resources for heating which will be 'green' (Van Herwijnen et al., 2003)] and some qualitative [Sustainable Rijnmond: 'To *C* or not to *C*, that's the question'; vision describing a transition to carbon-free and renewable carbon-based Rijnmond (Bosma et al., 2003)]. In addition, 80 ideas (70 proposals) for transition experiments were collected in the areas of new gas, biomass, energy efficiency and industrial ecology.

Simultaneously to the development of the sub-trajectories, the ministry tried seriously to alter the existing financial instruments so that they fitted the ET. New policy and financial instruments were developed, such as the 'Regeling Ondersteuning Transitie Coalities'' (Support Transition Coalitions, OTC) for transition experiment coalitions and the 'Unieke Kansen Regeling' (Unique Opportunity Scheme, UKR) of 35 million euro for transition experiments. In order to qualify for support, the experiments should

- be part of an official transition path
- involve stakeholders in an important way
- have explicit learning goals for each of the actors of the consortium.

For transition experiment coalitions, a total budget of 1.5 million euro was made available for feasibility studies with a maximum support of 50,000 euro per coalition. Both instruments came on top of the 173 million euro for energy innovation. The ministry's budget for transition policies is estimated to have risen from around EUR 200.000 in 2000 to roughly EUR 80 million for 2005. Part of this budget is 'relabelled' money, which would otherwise also have been invested only in more traditional energy research and experiments. Part of the money, however, is in new funds such as the UKR and the OTC funds. Besides these investments, the ministry is also committing a growing number of officials to the process, creating an evolving learning community within the ministry. Two other noteworthy funds are the Bsik-funds, a national research fund of over EUR 800 million, out of which close to 200 million is spent on innovative energy research, and the Energy Research Subsidies (EOS) which is now directly linked to the ET.

In its role as facilitator, the ministry has also undertaken efforts to remove institutional barriers. A good example is the Trendsetters Desk, a government service point that is meant to service initiators of experiments and transition-related activities. This includes both financial support and support in the areas of policy and legislation. For example, it helps businesses whose ET projects are hampered by permits, legislation or regulations, but is also frequently visited by Small and Medium Enterprises (SMEs). The Trendsetters Desk looks for solutions to the bottlenecks. The service point received some 50/60 questions in 2005, but in 2006 received over 10 a month. Most questions come from SMEs and relate to financial and institutional barriers. An interesting observation is that most of the problems could be solved, the only category in which only a very small percentage of the problems could be dealt with was 'government coherence'. In 2005 a platform for sustainable mobility was added to the ET (previously a separate transition process), and in 2006 two new platforms on sustainable electricity and on energy and built environment were established.

The activities of EZ have been quite successful. During the 5-year period, the experimental transition management process has matured and the result is the commitment of hundreds of professionals that share the agenda and carry out innovative projects. In addition, the transition management process contributed to the increased sense of urgency and political attention. According to the ministry itself, the transition approach gives new impulses to the innovation system in three ways (EZ, 2004):

- the process of visioning in the sub-trajectories with active involvement of business, governments and societal organisations and knowledge institutes, resulting in shared sense of direction

- novel coalitions have been founded of parties who traditionally were each others' enemies (an example being the biomass coalition of business and the environmental movement and the involvement of Greenpeace in offshore wind energy)
- niche markets are being sought for a number of transition paths.

In the next section, there will be a reflection upon the process by using the energy transition management principles formulated in Section 4. When the ministry started, the transition management concept was sketched only roughly. It has engaged in transition management as a side-track next to regular energy and innovation policy. Since then, the concept has been further developed in three co-evolving fields: theoretically by scientists, as an operational policy-process by policymakers and as an energy governance approach involving all sorts of practitioners. One of the consequences of the openness of this process is that it has grown into a learning network in which there is strong co-production of knowledge. It is co-evolutionary in the sense that new insights from each side of the science–policy–practitioner triangle influence the direction of the whole, all adapting to the questions or insights one has. This is exactly what one desires in terms of social learning for transitions. The reflection in the next section could contribute to this.

6 Reflection upon the energy transition management process

6.1 Approach the energy system as a complex adaptive system in its environment

In hindsight, it seems that the ministry in the first phase underestimated the importance of providing a solid basis for the transition management process in terms of system analysis, problem structuring and development of an integrated process approach. In terms of analysis and in terms of process, the transition analysis was limited to the supply side and (primarily the) regime actors from the energy field. In a sense the ministry presumed that the problem was already well-defined. Although a scenario study was part of their preparatory stage, the scenarios were not based on a systems' perspective but explored possible societal futures and different energy sources in these futures. This way they primarily focused on subsystem level and on energysupply in the Netherlands. They did, however, include mobility and housing as issues and are currently also developing interaction with other transitions in water, agriculture and chemical industry.

Although the focus thus widened during the process (also including overall visions and actor-groups, increasing attention to demand-side and related societal regimes), the focus is still on the existing regime and the supply side. In other words, by limiting the 'energy transition' to an issue of creating sustainable energy business, the behavioural, institutional, structural and cultural changes needed are more or less ignored. The ministry so far left out important dynamics in the areas of politics, innovation policies, innovative outsiders and alternative lifestyles. Because such elements and developments were not involved, the reflexive element of the ET remains limited to the existing and dominant elements and dynamics within the area of industry and technology. Although already a major step forward from the fragmented and purely bottom-up approaches in the 1990s, the ET so far thus does not yet fully benefit from the systemic approach underlying transition management.

In the context of the ET, governance strategies were developed at all three levels (strategic, tactical and operational) to deal with the internal system dynamics. Best developed are the tactical level, at which platforms, transition paths and transition agendas are developed, and the operational level, at which transition experiments are developed and funded. At the strategic level, the forecasting studies and the long-term vision were developed, and in 2005 the Taskforce and the IPE were established. However, a fundamental reflection on problems, their origin and the future of a sustainable energy system were so far barely touched upon. Although the experiments also involve societal and institutional aspects, they are still insufficient to amount to a fundamental debate, let alone change, at the level of societal culture and structures. Such debate can induce a broader public interest and participation in the problem-structuring process, something that is undoubtedly important for the development of support for measures, creating awareness and involvement (Van de Kerkhof, 2004). When debate did occur, it was not (systematically) influenced by the ET. Except for the taskforce and some debate initiated by individuals, a high-level public and political debate around sustainable energy seems to only have been really sparked since visits from Al Gore and Bill Clinton to the Netherlands. The ET has not really influenced regular policies such as investments in traditional research and technology, existing unsustainable infrastructures, resource use and consumption. In other words, the selection environment in societal and regime terms is changing, but more autonomously than as a result of active governance, while this is an essential role for government in transition management. Based on the outcomes of ET, the ministry can develop strategies and actions to influence the selection environment (existing regulation, markets, consumption, etc.) in a more top-down approach and role.

6.2 Deal with uncertainties

Most important uncertainties related to the energy issue are energy prices and availability, development of new technologies and resources. The ET did explicitly take these uncertainties into account by developing a portfolio of options and strategies based on scenario studies. The ministry executed a forecasting scenario study and an assessment of sustainability-related problems. They did also establish a forecasting trend analysis in which issues such as climate change, instability of oil-supplying regions and energy prices were seen as critical factors. Obviously, these issues all came to the forefront the past 5 years, which has stimulated the ET. The second outcome of the explorative preparatory phase was to focus the attention on a number of energy options present in any scenario. In terms of anticipating, the process has this way proven to be context-aware and based on different themes that are still, perhaps even more than when they were selected, relevant. In terms of dealing with uncertainties, a portfolio strategy of exploring multiple options simultaneously has so far proven to be a relatively 'safe' approach. This can also be said of the way that the processes and the outcomes are structured within the different themes. For each theme a portfolio strategy was developed (the transition agenda's), in which target images are related to different transition paths that in turn comprise multiple experiments. At the operational level, the ET has been successful in addressing innovators, supporting and setting up transition experiments (over 70) and creating attention within the energy-related community. A number of concrete successes such as the Heating Company and the Energy-producing Greenhouse illustrate this.

6.3 Approach the transition as a multi-actor problem solving process

The basic starting point for the ET was a multi-actor process in which public–private cooperation was sought and government acted mainly as facilitator and possible partner, rather than director or central authority. It seems that the mere idea of 'energy transition' has provided a shared goal, which helped actors to relate, cooperate and develop a sense of common responsibility and possibility. So far, the involvement has been mainly realised within business, science and NGOs, and those groups most active were perhaps already involved in the issue. In that sense, although it has led to more convergence of interests and more cooperation within the sector, the question is whether the fundamental issues related to the desired transition are addressed when consumers and citizens are so far not involved. The ministry, perhaps in its desire to achieve concrete results and to stimulate business, opted for the creation of networks within themes that already had ongoing developments and where large companies were active. The focus was on creating business based on the belief in market forces to facilitate the transition to a sustainable energy system. In terms of transition management, however, the ministry did not sufficiently involve private outsiders and civil society. The few large companies that dominate the present Dutch energy system are also dominant in the ET, as reflected in the Taskforce composition. At the level of the platforms more niche-actors are involved, but it has proven to be difficult to organise interaction where niche and regime actors treat each other like equals.

6.4 Stimulate new combinations

In terms of new connections at the tactical level, one of the major results of the ET is an inter-departmental cooperation between five ministries. This has resulted from the emerging interactions and obvious overlap between different domains and strategies. Also at the operational level, new coalitions and integrated projects have been developed, for example, the Heating Company (involving different types of actors). In a general sense, the ET creates room and direction for interaction and cooperation, thereby enhancing the chances for new combinations. They require, however, hard work, especially by the government who should facilitate this process through regulatory and financial action. The ministry did set up the Trendsetters Desk helping innovators, but much more should be done to discourage unwanted combinations and enable new ones. Striking example are the difficulties the Heating Company encountered in terms of regulations prohibiting cooperation between industry and government and between government and housing companies. The actions needed from government should be formulated at the strategic level and be part of the reflexive debates within the IPE, Taskforce and similar forums. So far this reflexive process has been underdeveloped, meaning that the attunement between the different levels of transition management both in terms of substance and process is absent: because a process architecture is missing, there is neither a convergence between vision, images, paths and experiments nor a convergence between innovative regime-actors and innovative outsiders.

6.5 Be reflexive in the management approach

It is already remarkable that it has been possible to develop a radically innovative governance approach in the context of an existing energy and innovation policy regime.

The ministry struggled to overcome existing routines, structures and culture and in a sense did not yet succeed in doing so: the market- and technology-based approach is still dominant, as is the bottom-up approach and the limited role of government as facilitator. Although this facilitating approach is highly flexible, adapting to changing compositions of networks, new initiatives and actions developed, it is still relatively close to the regular policies and approach. It is, however, remarkable to see how the ministry itself has, by implementing transition management, gradually learned, adapted and innovated their own practices and therewith influenced their own (policy) culture.

This is illustrated by their reaction to discussion about a perceived lack of strategic governance activities, the strong focus on supply side and the emphasis on technological innovation. In all areas the ministry has developed new initiatives because of criticism, debate and internal evaluation. Especially, the internal evaluations combined with broader debates between energy officials and experts has led to a new and evolving way of thinking about the role of government in this transition and how they should operationalise this role. It is therefore an excellent example of policy learning in which concrete experiences as well as analytical discussion and evaluation related to an ideal–typical transition management gradually lead to improved processes and governance: an example of learning-by-doing and doing-by-learning. Perhaps, even of more importance than the learning that occurred within a small group of directly involved individuals, the changes in thinking and acting also diffused more widely within the ministry and to other ministries via the inter-departmental cooperation.

The ET started out as an experiment, but by now has gained so much speed, drawn so much attention and involved so many actors that it can no longer be regarded as an experiment. Already noticeable is the regimes' response strategy that aims to bring the ET into the mainstream. For the coming years, it will therefore be crucial to build further on the achieved successes, claim and create new space for innovation and learning, and maintain a reflexive approach. However, the dynamics will necessarily shift more towards harvesting concrete successes, realising fundamental changes in the regime and diffusing the process on a wider scale, at least to involve consumers. This will evidently require new and adapted strategies, approaches and instruments, which in part need to be discovered, developed and tested. Evidently, this is at the heart of managing transitions: learning-by-doing and doing-by-learning.

7 Conclusion

The current energy system is deeply embedded in our economy, consumption patterns, regulations and infrastructure. However, transitions to radically different energy systems are inevitable. The uncertainties about these future transitions are high, which is one of the reasons why different actors make different assessments regarding the urgency of the problem and the desired direction. Historical analysis suggests that the Dutch energy system is currently in the pre-development phase, possibly near take-off. Important is to understand that the history of our energy regime determines to a large extend the possibilities for shaping and governing a desired transition to a sustainable energy system. This implies that we need to consider time frames which are much longer than normally used in policy. It also implies that new kinds of governance are needed to manage to transition to sustainable energy systems. The complexity of the energy transition, the changing role of the national government in the energy system and the importance of developing a sustainable energy system have led the Dutch government to start with energy transition management.

Based on transition theory and the historical analysis of the Dutch energy system, several starting points for energy transition management have been suggested that are translated into an operational transition management strategy (Rotmans and Loorbach, 2006). This strategy distinguishes between strategic, tactical and operational levels of governance and between four activity clusters. Reflecting on the way the Dutch Ministry of Economic Affairs implemented energy transition management – using transition management as an evaluative framework – we conclude that it contributed to the convergence between actors in the field, to a strong innovation dynamic that includes domains outside the primary energy domain and growing acknowledgement of the need for change. The involvement of hundreds of actors, from business, science, government, NGOs and others, has laid a fruitful basis for further experiment, development, change and innovation in this field. However, based on our analysis, the ministries' approach so far, has not addressed all energy transition management principles to the fullest. Important reason for this was that the transition management process itself was embedded in the existing structures of the ministry, which are likely to constrain radical experimentation. Nonetheless, the ministry showed a strong reflexive capacity and continuously improved the process. In this late pre-development phase of the upcoming transition, government should – aside from facilitating innovation – also select those innovations that fit their sustainability vision and discourage innovation that supports existing regimes. The energy transition management has been quite successful as an experiment in reflexive governance. The coming years will show whether the developed transition networks and innovation agendas will break through to regular policies and networks, and thereby actually lead to the desired structural changes in the Dutch energy system.

Acknowledgements

We would like to thank the editor, the reviewers and our colleague Roel van Raak for their very helpful comments that helped to improve the paper.

References

AWT (2003) *Backing winners, van generiek technologiebeleid naar actief innovatiebeleid*. Advies nr. 53, The Hague.

Bosma, A., Brouwer, G., Diepenmaat, H., Jordan, C., Van Soest, J.P., Van Toledo, G. and Van der Weiden, A. (2003) *To C or not to C, that's the question*. Vaison-lla-Romaine/Rotterdam, ROM-Rijnmond.

Cavallo, A. (2004) 'Predicting the peak in world oil production', *Natural Resources Research*, Vol. 11, pp.187–195.

CBS (2005) *Duurzame energie: capaciteit, productie en vermeden primaire energie*. Voorburg/Heerlen, Central Bureau for Statistics.

Correlje, A.F., Linde, C.V.D. and Westerwoudt, T. (2003) *Natural gas in the Netherlands, From cooperation to competition?*. Amsterdam, Oranje-Nassaugroep.

Dirven, J., Rotmans, J. and Verkaik, A. (2002) *Samenleving in transitie: Een vernieuwend gezichtspunt*. Den Haag, Innovatienetwerk Agrocluster en Groene Ruimte.

Eising, R. and Kohler-Koch, B. (1999) 'Introduction: network governance in the European Union', in B. Kohler-Koch and R. Eising (Eds), *The Transformation of Governance in the European Union*. London: Routledge.

Energieraad, V-R. (2004) *Energietransitie: Klimaat voor nieuwe kansen*. 's Gravenzande, Energieraad, VROM-raad.

Ez (2000) *Energie en samenleving in 2050, Nederland in wereldbeelden*. Den Haag, Ministry of Economic Affairs.

Ez (2001) *Investeren in Energie: keuzes voor de toekomst*. The Hague, Ministerie van Ez.

Ez (2003) *Sturen naar het zuiden. Een vernieuwd overheidsoptreden om de energietransitie op weg te helpen*. Den Haag, Ministry of Economic Affairs.

Ez (2004) *Innovation in Energy Policy*. The Hague, Ministry of Economic Affairs.

Geels, F.W. (2002) *Understanding the Dynamics of Technological Transitions: A Co-evolutionary and Socio-technical Analysis*. Centre for Studies of Science, Technology and Society. Enschede, Universiteit Twente.

Geels, F.W. and Kemp, R. (2000) *Transities vanuit sociotechnisch perspectief*. Maastricht, MERIT.

Loorbach, D. (2007) *Transition management. New mode of governance for sustainable development*. Utrecht: International Books.

Loorbach, D. and Rotmans, J. (2006) 'Managing transitions for sustainable development', in X. Olshoorn and A.J. Wieczorek (Eds), *Understanding Industrial Transformation. Views from Different Disciplines*. Dordrecht: Springer.

Meadows, D., Randers, J. and Behrens, W. (1972) *The Limits to Growth: a Global Challenge*. New York, Club of Rome.

Midgley, G. (Ed.) (2000) *Systemic Intervention: Philosophy, Methodology and Practice*. New York: Kluwer Academic Publishers.

Rip, A. and Kemp, R. (1998) 'Technological change', in S. Rayner and E.L. Malone (Eds), *Human Choice and Climate Change*. Columbus, OH: Battelle Press.

Rotmans, J. (1994) *Transitions on the Move. Global Dynamics and Sustainable Development*. Bilthoven, The Netherlands: Rijksinstituut voor Volksgezondheid en Milieu (RIVM).

Rotmans, J. and Loorbach, D. (2007) 'Transition management: reflexive steering of societal complexity through searching, learning and experimenting', in J.C.J.M. Van den Bergh and F.R. Bruinsma (Eds), *The Transition to Renewable Energy: Theory and Practice*. Cheltenham, Edward Elgar.

Rotmans, J., Kemp, R. and Van Asselt, M. (2001) 'More evolution than revolution: transition management in public policy', *Foresight,* Vol. 3, p.17.

Schot, J., Lintsen, H., Rip, A. and Albert de la Bruheze, A. (Eds) (2000a) Delfstoffen, energie, chemie, Eindhoven, Lecturis BV.

Schot, J., Mom, G., Filarsky, R. and Staal, P. (2000b) 'Concurrentie en afstemming: water, rails, weg en lucht', in J.W. Schot (Ed.), *Transport*. Eindhoven, Walburg pers.

SER (2001) *Ontwerpadvies Nationaal Milieubeleidsplan 4*. Den Haag.

Tellegen, E., de Jong, P., Slingerland, S., Wijmer, S. and Wolsink, M. (1996) 'Nutsbedrijven en de beperking van huishoudelijk milieugebruik in Nederland', in B.E.A. Van Heerikhuizen (Ed.), *Milieu als mensenwerk*. Groningen, Wolters-Noordhoff.

Van Asselt, M. (2000) *Perspectives on uncertainty and risk: the PRIMA approach to decision support.* Maastricht, Proefschrift, Universiteit Maastricht.

Van de Kerkhof, M. (2004) *Debating Climate Change*. Utrecht, Lemma.

Van der Brugge, R., Rotmans, J. and Loorbach, D. (2005) 'The transition in Dutch water management', *Regional Environmental Change*, Vol. 5, pp.113–135.

Van Herwijnen, T., Schoof, A., Faaij, A., Bergsma, G., Loorbach, D., Schaeffer, G.J. and de Keizer, I. (2003) Visie op biomassa. De rol van biomassa in de Nederlandse energievoorziening 2040 [Vision on biomass. The role of biomass in the Dutch energy supply 2040]. The Hague, The Netherlands, Ministry of Economic Affairs.

Verbong, G. (2000) *De Nederlandse overheid en energietransities: Een historisch perspectief*. Eindhoven, Stichting Historie der Techniek.

Verbong, G., Vleuten, E.V.D. and Scheepers, M.J.J. (2002) *Long-term electricity supply systems dynamics: a historic analysis*. Petten, ECN.

Verbong, G., Berkers, E. and Taanman, M. (2005) Op weg naar de markt: de geschiedenis van ECN 1976-2001, Petten, Energieonderzoek Centrum Nederland.

Voss, J-P. and Kemp, R. (2005) 'Reflexive governance for sustainable development. Incorporating feedback in social problem-solving', Paper presented in the Proceedings of the *ESEE Conference*. Lisbon.

Vringer, K. and Blok, K. (2000) 'Long-term trends in direct and indirect household energy intensities:a factor in dematerialisation?', *Energy Policy*, Vol. 28, pp.713–727.

VROM (2001) *Where there's a Will there's a World*. The Hague, VROM ministry.

Note

[1]These guidelines are based on the analysis described in the previous sections, which suggests that the energy transition is in a pre-development phase. Other phases will require different strategies (Loorbach, 2007).

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