ESPOO 2008

VTT WORKING PAPERS 99

System Transition

Concepts and Framework for Analysing Nordic Energy System Research and Governance

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ISBN 978-951-38-7160-4 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1459-7683 (URL: http://www.vtt.fi/publications/index.jsp)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT, Vuorimiehentie 3, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 4374

VTT, Bergsmansvägen 3, PB 1000, 02044 VTT
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phone internat. +358 20 722 111, fax +358 20 722 4374

Technical editing Anni Repo

Text preparing Tarja Haapalainen

Series title, number and report code of publication

VTT Working Papers 99
VTT–WORK–99

Author(s)
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Title

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Abstract

System transitions are complex societal co-evolutionary processes that are typically led by gradual adaptation rather than visionary management or coordination. Still, visionary coordination of policies, regulation, corporate strategies and social learning may overcome some barriers and foster new innovation efforts providing sufficient impetus towards system transition. Building on earlier literature and experiences on system transitions and related research and governance, this paper develops an analytical framework. This framework integrates different transitions phases, levels and dimensions and combines them with the governance functions to provide overarching frames for understanding system transitions. While the framework is developed keeping in mind its application in the Nordic energy system transition research and governance, it may also be applicable in other sectors. For the didactic purposes, the paper applies the framework in the analysis of the three energy sector projects by positioning them in the developed framework. Further in-depth analysis of recent and on-going research and governance efforts may provide a good basis to identify relevant synergies and areas for future developments. Moreover, the use of such an overarching transition framework supports the coordination efforts between many sometimes even controversial efforts in the development of energy systems.

ISBN
978-951-38-7160-4 (URL: http://www.vtt.fi/publications/index.jsp)

Series title and ISSN		Project number
VTT Working Papers 1459-7683 (URL: http://www.vtt.fi/publications/index.jsp)		23145
Date May 2008	Language English	Pages 42 p.

Name of project	Commissioned by
GoReNEST	Nordic Energy Research, VTT Technical Research Centre of Finland

Keywords	Publisher
energy system transition, innovation, transition management, techno-institutional change	VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT, Finland Phone internat. +358 20 722 4520 Fax +358 20 722 4374

Preface

The Nordic countries – Denmark, Iceland, Finland, Norway and Sweden – have a good reputation where societal welfare, education and a clean environment are considered. They are also among the leading countries with regard to innovation and competitiveness measures and indicators. It is thus natural to expect that Nordic actors take a proactive role in participating in the global and regional energy system transition processes that aim at sustainable development. This presumes also a good understanding of the governance of the transition processes. This working paper is contributing to this end.

The proactive role in global energy transition means that the Nordic countries actively search and adopt sustainable energy technologies and that they actively participate in developing new energy technologies and services that support sustainable developments. The Nordic countries should take an active role in facilitating sustainable developments also globally, including even the new economies and developing countries. To make this a genuine win-win strategy, the Nordic actors should also actively utilise new business opportunities related to the global energy transition. Proper governance tools are needed to reach these aims.

This working paper is the first deliverable of the GoReNEST project – one of the innovation policy studies funded by Nordic Energy Research in 2007–2008. The innovation policy study program was launched by Nordic Energy Research in the beginning of 2007. It aims to aid Nordic decision-makers in their processes for developing efficient policies on science, technology and investment in new energy technologies and systems. This is intended to strengthen the Nordic research and innovation (R&I) area in new energy technologies and systems.

The innovation policy studies funded by NER examine the Nordic energy innovation policy from different perspectives, applying knowledge from several complementary disciplines. They provide insight into Nordic energy research and innovation systems by developing indicators and analysis tools, mapping potentials of various technologies and policy instruments, developing recommendations for promoting investments, and investigating potential export markets for new Nordic energy technologies and solutions.

This working paper has been compiled by researchers with special expertise in transition management and innovation systems. The aim of the authors is to bring new insight into the governance of energy systems transition, especially when examined from the Nordic actors' point of view. The ingredients of the working paper are drawn from relevant theories and empirical work.

The paper also serves the subsequent steps of the GoReNEST project by providing a conceptual framework for further analyses and stakeholder involvement. In particular, Nordic research activities are analysed in the GoReNEST project from the viewpoint of their ability to support the energy system transition. On the other hand, the conceptual framework is applied to the analysis of the governance and funding practices that are intended to support the energy system transition. It is also used as a means for facilitating stakeholder dialogues that contribute to this aim. The subsequent steps of the GoReNEST project thus provide an opportunity to fine-tune and elaborate the conceptual framework so that it can be successfully applied for the purposes of policy-making, governance and designing of proper instruments for the Nordic energy system transition. The overall results are reported in the final report of the GoReNEST project.

Contents

1. Introduction

Given the severity of global warming and security threats in energy supply, it is considered urgent to develop common action plans to foster energy system transitions. Towards this end, the post-Kyoto agreement as an efficient and common international framework for climate mitigation is still to be negotiated. In particular, the European Union has been proactive and has recently committed to a strategic energy policy objective: by 2020, the EU will reduce its greenhouse gas emissions by at least 20% compared to 1990 levels, increase its renewable energy to 20% and increase energy efficiency by 20%. Furthermore, according to the Commission estimates, by 2050 global greenhouse gas emissions should be reduced by 50% compared to 1990 levels, implying reductions in industrialised countries of 60 to 80% compared to estimated emissions with business as usual scenario.

Such challenges mean potential new socio-economic threats to Nordic welfare (e.g. in terms of energy and food security and future competitiveness), but also important business opportunities. They offer opportunities for those who proactively address the need for change to develop Nordic energy systems and to aim at global markets with new technologies; like Danish companies previously with wind turbine technology. However, the global challenges require changes beyond *incremental and continuity type of*[i] performance improvements of present practices. They call for *transitions towards radically different systems*, major technology shifts in energy sector, towards the rapid diversification of energy production and efficiency in energy use addressed also in the recent Strategic Energy Technology Plan for Europe. Taking advantage of the need for renewal of the existing energy system at large requires, though, an insight into the process of how large socio-technological systems emerge and evolve. This knowledge can then be used to gain insight into how a transition towards a sustainable energy system can be best facilitated; how opportunities for developing new systems and profiting from new innovations[ii] can be achieved.

Transitions towards radically different systems are complex societal co-evolutionary processes that are typically led by a series of gradual and parallel adaptations rather than visionary management or coordination. Indeed, several authors have argued that desired transitions are difficult to initiate and achieve, because the prevailing system acts as a barrier to the creation of a new system. Still, visionary coordination of policies, regulation, corporate strategies and social learning may overcome some barriers and foster new innovation efforts providing sufficient impetus towards system transition. Here, it is crucial to link long-term visions with the short and medium term strategies to generate favourable industrial, policy and social conditions leading to common action towards transition.

The recent transition[iii] theorising on institutional and technological changes provides a firm premise to understand the challenges related to such systemic change and the corresponding governance responses. Building on Rotmans et al. (2001) and for the purposes of this paper on energy system transitions, we characterise *system transition* as follows:

i) It deals with a *long term* continuous change process with parallel developments in different phases (e.d. predevelopment, take-off, acceleration and stabilisation) leading to a radically new system.

ii) It takes into account developments on *different levels* (niche, regime and landscape, e.d. micro, meso and macro levels). On these levels it addresses technological, industrial, political and societal changes.

Despite a gradual policy application of transition approaches, especially in the Netherlands (e.g. the Fourth Dutch National Environmental Policy Plan 2001, and recent Transition Platforms) and diverse European (e.g. BLUEPRINT, 2003) and some Nordic research projects (e.g. Kivisaari et al., 2004), the unfamiliarity and lack of experience in Nordic countries have meant that their use in policy-making and governance has received insufficient attention. Thus, efforts in applying these perspectives for supporting the Nordic actors' proactive participation in the global energy transition have been quite limited or rather loosely coordinated so far.

This paper addresses 'system transition' as a valuable perspective and develops a framework for analysing Nordic energy system research and governance. Thus, the goal is not to suggest the replacement of existing research or governance efforts but rather enhance their combined use, identify and benefit from potential new synergies and streamline the efforts towards more coordinated common actions in Nordic countries.

The paper is structured as follows. Section 2 develops a general framework for the research and governance of system transitions. Building on the framework, Section 3 elaborated different governance functions. In Section 4, this framework for transition research and governance is discussed in view of energy system transitions. Finally, Section 5 concludes the paper.

The Framework is applied and elaborated in other Tasks of the GoReNEST. In Task 2, the framework is applied and elaborated in the analysis of Nordic energy research activities in support of energy and climate policy and governance towards energy system transition. In Task 3, the framework is also applied and elaborated in the analysis of governance and funding models and practices that can be applied to innovative energy programs and initiatives in order to support system transition. In Task 4, the framework is used as a communication tool among Nordic energy sector stakeholders to communicate selected issues related to system transitions. In Task 5, the framework is fine-tuned and included in the final report of the project.

2. Framework for System Transition

2.1 Introduction to System Transition

Research on techno-institutional transition draws upon a large range of different disciplines such as evolutionary economics and technological change theories, sociology and political sciences, communication theories, geographical clusters theory and knowledge management, among others. Such approaches characterise the technology as knowledge[iv], of which the creation and exploitation is highly dependent on available resources including various capabilities and time. These premises are, for example, in line with the work of Michael Porter on national competitiveness and the related concept of *geographical clusters* (1990, 1998), which have been influential in cluster-based innovation and industrial policies in Nordic countries.

Within the knowledge based premises, the term 'technology' must be understood as involving both a body of artefacts, practice, and a body of understanding, which co-evolve with each other over time. From this perspective, technological systems are best understood as being composed of both *physical technologies* – in the form of components, combined systems and infrastructure, and *social technologies (institutions)* – in the form of social patterns, constrains and mechanisms of behaviour such as social norms, routines, legislation, standards and economic incentive mechanisms[v].

Among other disciplines that address technology as knowledge, evolutionary economics[vi] aims at a more realistic modelling of societal changes even with the expense of the increased complexity and related difficulties that it lays on the modelling of economic systems. Within these fields, our transition theorising addresses:

- Diversity
- Bounded rationality
- Uncertainty
- Multiple equilibria
- Path dependence
- Irreversibility.

Diversity refers to both economic actors and technologies. Actors such as enterprises and consumers are not perceived in a unitary way as optimisers that behave under the same rules or models. These actors influence on dynamic processes of innovation and selection[vii] of products and technologies. As such, technological development can also be understood as a process of evolutionary competition in populations of firms, in which alternative technologies compete with one another and with the dominant technology, resulting in selection of 'winners' and 'losers' on a market. This process has considerable *uncertainty* at the outset about which of these technologies will be eventual winners (Nelson & Winter, 1982). The uncertainty is further increased by the complex nature of techno-institutional systems, involving the development of not only technologies, but also industrial, policy and societal changes.

Given this intrinsic uncertainty in the process of technological change, the assumption of rational maximizing behaviour is rejected and replaced by *bounded rationality* (Simon, 1959, 1965) that leads to satisficing behaviour, e.d. people are prone to change their behaviour rules (routines) only when it is clear that these cannot lead to satisfactory outcomes (Fagerberg, 2003). As a result, there is no single welfare maximizing equilibrium, but rather possible *multiple equilibria.* Historical irreversible and path dependent processes determine which equilibrium is reached or approached at any given time.

Path dependence refers to that directions for future development are foreclosed or inhibited by directions in past development, as most innovations build on past discoveries and need to adapt to pre-existing conditions for successful diffusion[viii]. The path-dependent and irreversible nature of techno-institutional co-evolution makes transitions[ix] difficult to achieve; the prevailing system acts as a barrier to the creation of a new system.

These phenomena, in particular the existence of multiple equilibria gives a new rationale to the State's intervention in the economy, in that *coordination*[x] of the decisions by individual agents may be necessary in order to seek convergence between the particular and general interests (Moreau, 1999). The important questions relate to how well policy makers learn and adapt in the light of experience. The scope for policy is not to optimise with respect to some objective function (e.g. social surplus) but rather to stimulate the introduction and spread of improvements in technology. Hence, the main question is not optimization and equilibrium, but endogenous change, evolution and economic development (Llerena & Matt, 1999: 4). The focus of attention has ceased to be on the market failure *per se* and has moved to the improvement in competitive performance and the promotion of structural change and related "government" or "system" failures (Mowery & Rosenberg, 1989). The governance focus on a specific technology, product group, or industry is insufficient. Instead attention should be directed towards the evolution of the whole techno-institutional system.

Within a system transition, innovation can have different roles. Bessant and Tidd (2007) provide a typology for this along the dimensions of the novelty of the knowledge involved in these innovations, and the novelty of the application of such knowledge (Figure 1).

Knowledge \ Application	Existing	New
New	Development of alternative technologies in existing applications	Co-evolution of new Techno-institutional systems
Existing	Incremental improvements in the performance and quality of existing products and services	Creation of novel product and service niches

Figure 1. Roles of innovation in the system transition (modified from Bessant & Tidd, 2007).

All in all, social and political believes and concerns form an important, yet mostly subtle influence on the *rate*, but mostly the *direction* of system transition. Traditional, formal, and direct policy intervention (such as regulation and control) which tries to influence such processes may still be useful (Bessant & Tidd, 2007). However, a more balanced and effective approach is needed to gain deeper understanding on the complex interactions and processes of co-evolution. Therefore, Section 2 develops a general framework for the research of transition. This framework consists of three key elements of the transition process:

- Four phases of transition process including predevelopment, take-off, acceleration and stabilisation
- Three levels of analysis including niche, regime and landscape
- Four dimensions of the transition, including technological, industrial, policy and social change.

Subsequently, these elements are described in more detail and finally brought together in a common analytical framework.

2.2 Phases of Transition

Techno-institutional systems tend to go through long periods of relative stability, which is followed by shorter periods of structural change, 'transition'. Hence, in the historical continuum, the transition represents a non linear change (Rotmans et al., 2001), however, the process of transition is gradual one, and follow transition phases that reflect an S-shaped-curve[xi] (see also Figure 2 and Box 1):

- *Predevelopment* (incubation) with the diversity of experimentation activities.
- *Take-off* of the process of transition.
- *Acceleration* of the change process with the increasing returns of economies of scale that support the diffusion of new solutions and lead to structural change.
- *Stabilization* with the decreases in the speed of societal change.

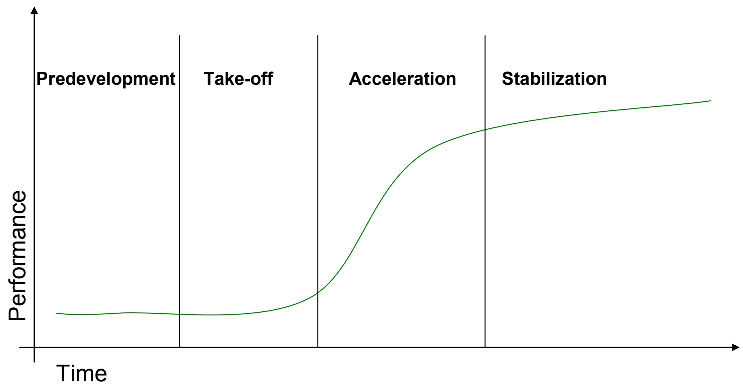

Figure 2. The S-curve and the phases of transition.

The transition is a complex multidimensional societal change process dealing with the co-evolution of technological, industrial, policy and social changes. The S-curve is highly simplified illustration of such a process, developed to conceptualise the development and diffusion of an individual technology.

Box 1. S-shaped curve of technological performance

According to Foster (1986: 96)[xii], an S-shaped curve (Figure 1) shows how the performance of a technology improves in comparison with the effort used to develop it. In practice, much of this development is the result of economies of learning, which in turn depend on the level of adoption and the experience of users.

Returns are not constant with the growth in the adoption of the technology. This fact derives to a large extent from the increasing returns which can accelerate the rate of improvement compared with competing alternatives. After a point of inflection, the possible improvements in performance are progressively smaller, and eventually reach a limit (stabilization) at which there is no further improvement even if new users are added (Moreau, 1999: 9; Laffond et al., 1999; Loch & Huberman, 1999: 12).

As greater production experience is acquired, producers learn how to make additional units more cheaply (learning by doing) (Arrow, 1962a, b). Greater experience is also acquired in their use, and users' productivity increases (learning by using) (Sheshinski, 1967). Positive externalities occur because the physical and informational networks are more valuable to users as they grow in size (Katz & Shapiro, 1985, 1986a,b; Farrell & Saloner, 1986a, b; Economides, 1996). As the number of people adopting a given technology grows, so the uncertainty is reduced and both the users and producers perceive reduced risks in its adoption. Their confidence in the quality and performance of the technology and perception of its likelihood of continuing to be available in the future therefore increases (Arthur, 1991). At the same time, the increase in the number of users reduces information search costs (Blackman, 1999). Thus, as an alternative technology gains market share, potential users have an increasingly powerful incentive to adopt that alternative, provided they are able to exchange information with those users who already have the technology.

According to Anderson and Tushman (1990), all areas of industry advance through a series of technology cycles. Each of these cycles begins with a technological discontinuity, triggered by the emergence of a breakthrough innovation, which significantly advances – by more than an order of magnitude – the state of the art characterizing a given industry. Such innovations may be a result of cross-sectoral spillovers or long term continuous RTD efforts, for instance. In terms of Foster's (1986) curves, this discontinuity could be represented as a "jump" between two curves. In practice, the technologies are often interdependent and their co-evolution marks the success of their application.

Hence, the technological transition of systems could be seen as a gradual co-evolution of different technologies and illustrated as interplay of different s-curves. For example, in Figure 3, the interplay of the s-curves of fuelcells and hydrogen (H_2) storage, fossil combined heat and power (CHP) and biomass CHP lead to higher performance of the technology.

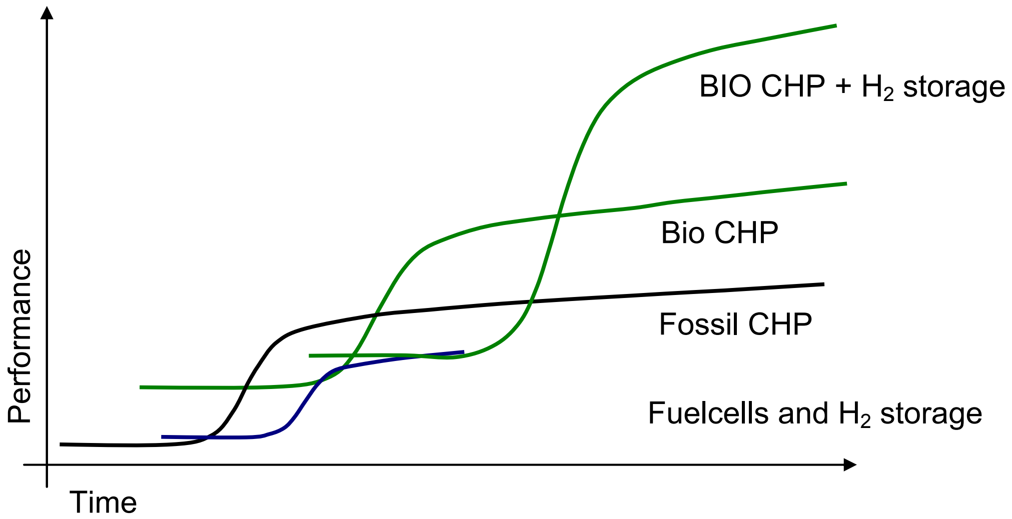

Figure 3. Co-evolution of technologies and their s-curves.

2.3 Levels of System Transition

Another key element of transition theorising (e.g., Rotmans et al., 2001) is the parallel analysis of societal developments in different levels, including niche, regime and landscape level developments. The multi-level 'niche-regime-landscape' analysis doesn't refer to multiple aggregation levels as such: the issues focused at each level are selected on the basis of their relevance to the specific system transition in hand. Specific attention is paid to the interconnections between these levels of analysis, focusing on issues relevant to the particular context in question. These three levels of analysis are briefly explained in the following subsections (see also Table 1).

Regimes

In the context of system transition, regime refers to the established mainstream techno-institutional policy, industrial and user system delivering a specific function in society; for example the carbon based energy and transport systems. Holtz et al. (in press) define five characteristics that regimes should at least in some extent possess, including: *purpose* (regimes relate to a societal function), *coherence* (regime elements are closely interrelated), *stability* (regimes are dynamically stable), *non-guidance* (they show emergent behaviour) and *autonomy* (they are autonomous in the sense that system development is mostly driven by internal processes). Thus, the specific form of the regime is dynamically stable and not prescribed by external constraints but mainly shaped and maintained through the mutual adaptation and co-evolution of its actors and elements. This regime can be challenged by other regimes and by wider socio-economic landscape (Geels, 2006) and specific niche developments (Kemp et al., 1998).

Niches

Geels (2006) describes 'niches' forming the level where radical novelties emerge that deviate from the existing regime. This deviation to the regime in view of the characteristics mentioned above marks the positioning of identified factors either to the regime or to the niches. Thus, emerging novelties that are not yet widely diffused do not automatically belong to a niche. Here, the important is the chosen level off analysis and the definition of the regime to make clear which novelties deviate from the existing regime. Geels (2006) continues that niches may take the form of small-market niches, where selection criteria are different from the existing regime. Survival of such niches may be supported by public subsidies and act as incubators for new technologies or practices. Niches provide opportunities for learning and incubation of alternative solutions that may gradually become strong enough to challenge the existing regime or adopt and transform the regime towards new directions.

Landscape

Kemp et al. (1998) as well as Geels (2006) define also third level of analysis named 'the socio-technical landscape', which forms an exogenous macro level environment that influences developments in niches and regimes. The socio-technical landscape tends to change only very slowly (for example, demographic changes, macro-economics, cultural change). While landscape developments refer mainly to national and international (Nordic/EU/global) developments, such societal conditions can also be identified on the local and regional level.

Table 1. Levels of system transition.

Level of analysis	Description	Examples
Landscape	Landscape forms an exogenous macro level environment that influences developments in niches and regimes.	Natural resources (e.g. global oil and gas reserves), climate change.
Regime	Regime refers to the established mainstream techno-institutional policy, industrial and user system delivering a specific function in society. The regime is dynamically stable and not prescribed by external constraints but mainly shaped and maintained through the mutual adaptation and co-evolution of its actors and elements.	Carbon-based electricity production, distribution and user system.
Niche	Niche forms the level where radical novelties emerge that deviate from the existing regime.	Solar energy systems, hydrogen energy systems.

2.4 Dimensions of System Transition

Further to the phases of transition and the levels of analysis, the analysis of systems transitions benefits from the identification of relevant dimensions of the societal change. Building on the earlier literature on techno-institutional transitions, Könnölä (2007) considers four dimensions crucial for understanding the emergence of systems innovation. The four dimensions consist of technological, industrial, policy and social change; described in more detail below (see also Table 2 for their core concepts).

i) ***Technological change.*** The identification of linkages between physical technologies (both components and their combined systems) as well as their different phases of maturity (from emerging to dominant design technologies) provides improved understanding not only on the present state of transition process, but it also helps identify major technological bottlenecks and opportunities for alternative technological future pathways. The systemic interconnections of technologies require interoperability referring to the ability of applications and their systems to work together within and across technological and organizational boundaries. Here, the interoperability of technologies becomes crucial for increasing returns of economies of scale (Arthur, 1994) that support the diffusion of the technology.

ii) ***Industrial change.*** The identification of networks of technology developers, providers and appliers (users) and related financing services (investors) improves the understanding of the key drivers and barriers for change in the system. The analysis of lobbying and standardisation efforts provides relevant information on the industry dynamics. In particular, industry-wide co-operation and standardisation efforts are typically directed to major interoperability problems. Hence, the exploration of existing and emerging standards and their supplementary or competitive inter-relations provide further understanding of the interrelatedness of different application and technology areas and their alternative future pathways. Furthermore, for the comprehensive understanding of the transition process, it is crucial to identify also the possible absence of lobbying and standardisation efforts in the relevant areas of alternative techno-institutional pathways. Towards further understanding of industrial change it is beneficial to explore also routines and competences that mark the conditions how organizations are able to create and exploit new technologies and other kinds of knowledge. Typically, the solutions that adapt to the existing organisational conditions are easier to implement, which lead to learning economies; skills and knowledge accumulate through learning-by-doing and learning-by-using (Arthur, 1994).

iii) ***Policy change.*** Policy frameworks, understood as broad institutional and legal frameworks, can function both as barriers and drivers for change. Policy change is bounded by path dependent organizational routines and competences. Historically, in Europe the legal and policy frameworks have been developed to correct and optimize the performance of society in view of the specific criteria in each policy area. Such optimization-oriented policy efforts may reinforce lock-in conditions to existing systems. On the other hand, new governance structure and evolutionary coordination policies are increasingly designed in particular in Europe to better respond to changing societal needs (Metcalfe, 1995), which are more concerned with facilitating technological and structural changes than imposing a particular result. Both policy-makers and other stakeholders tend to shape institutional context through their strategic actions of creating and claiming value (Powell & DiMaggio, 1991) and can help create new social networks and agreements which can open up possibilities for novel innovations.

iv) ***Social change.*** The success of technological systems depends also on the experience and response of the end-users and those closely affected by the system. Social change may create demand for emerging technologies but also hamper the diffusion of promising technologies. When changes emerge in the system, the end-users adapt their preferences and expectations on the system through the gradual acculturation and socialisation (Unruh, 2000). When increasing number of users adapt to the system, emerges adaptive expectations as increasing adoption reduces uncertainty. Alternatively, the changes may create counter-productive social behaviour that leads to inertia in the implementation of the new system functions. The examination of such societal conditions and expectations bring in the analysis not only the user perspective but also larger societal value systems.

These four dimensions provide the intertwined framework for the analysis of complex techno-institutional transition processes.

Table 2. Dimensions of system transition and related core concepts.

Dimensions of systems innovation	***Core concepts and elements***
Technological change	Dominant designs, emerging technologies, infrastructures, interoperability
Industrial change	Standards, value chains and networks, organisational hierarchies and practices, investment mechanisms, intellectual property
Policy change	Information services, networking, setting common agendas, strategic procurement, financing research and education, grants, equity support and fiscal measures, regulation and standards
Social change	Behaviour, routines, preferences, attitudes, values, user involvement

The technological system emerges through the gradual application and development of new technologies. Such a path dependent process is largely driven by industry dynamics, in which organisational resources, routines and competences define the value-networks and lobbying and standardisation efforts. This system is influenced by the policy change that participates in the system development through the establishment of market conditions and fostering (or hampering) both supply and demand. Policy change is in turn largely directed by social changes, which also mark the diffusion of the innovation (see Figure 4).

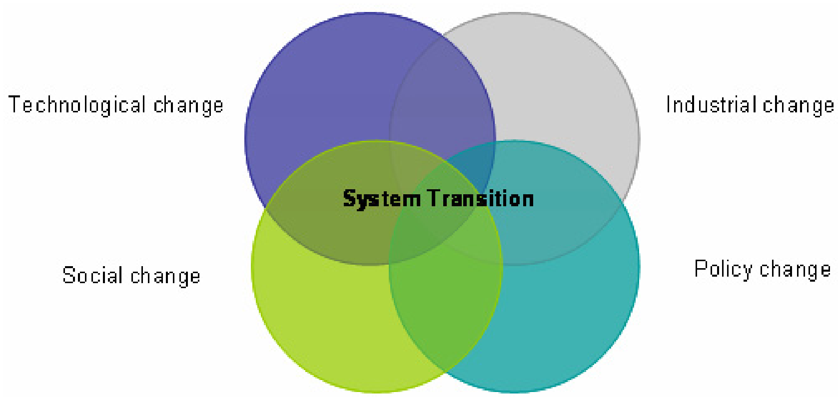

Figure 4. System transition builds on dynamic linkages between technological, industrial, policy and social changes.

2.5 Integrated Framework for Transition Research and Governance

The above described four phases of transition, three levels of analysis and the four dimensions of the system transition are important elements in the analysis of system transition. In particular, when these elements are combined to a common framework it is possible to identify transition drivers and barriers in more detail. The combined approach can be illustrated in the three dimensional presentation (Figure 5).

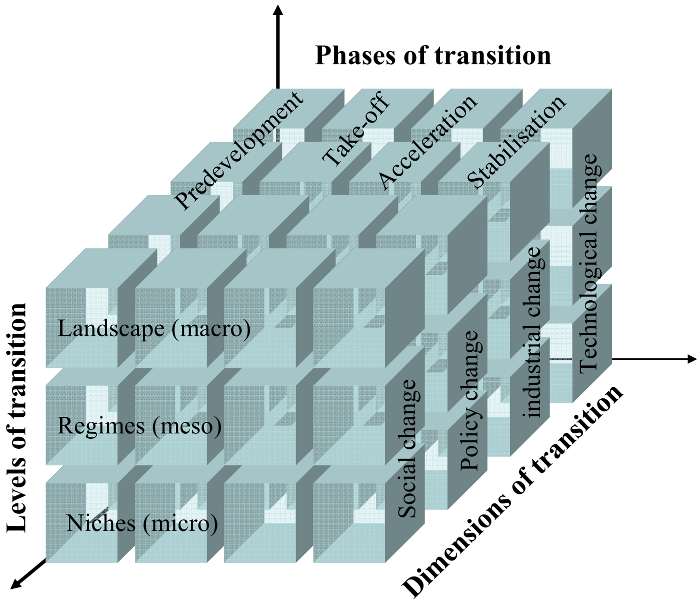

Figure 5. Phases, levels and dimensions of transition.

The three dimensional presentation supports the positioning of specific developments at one defined moment in time. However, this type of presentation is static leaving out time, which is crucial when evolutionary processes are dealt with. This framework needs to be adapted to the co-evolution of different technologies and systems that are likely to exist in parallel but in different phases of transition. Towards this end the transition phases can be replaced with the timeline that allows explicit analyses of the co-evolution of various transition phases within different dimensions and levels (Figure 6).

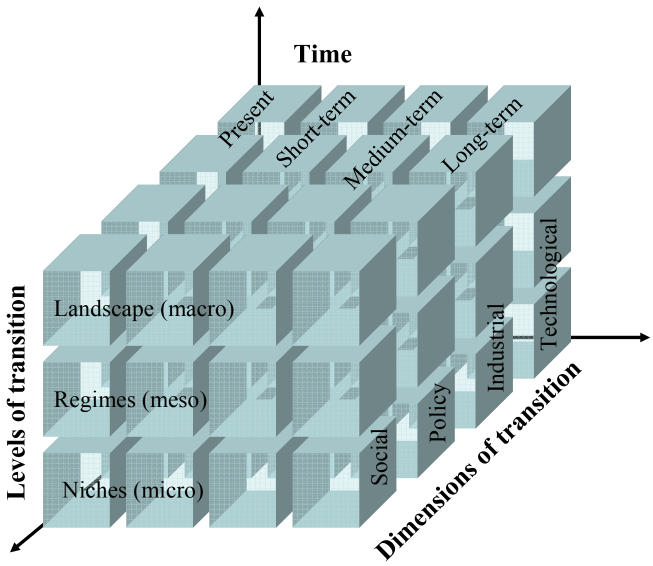

Figure 6. Time, levels and dimensions of transition.

The framework illustrated in Figure 5 can be transferred to tables in three different levels (see Tables 3a, 3b, 3c). Such a table can be applied in the analyses of the interrelations between the time, dimensions and levels.

Table 3a. Analysis framework for landscape level transition.

	Change dimensions	**Present state**	**Short-term change**	**Medium-term change**	**Long-term change**
Landscape	Technological				
	Industrial				
	Policy				
	Social				

Table 3b. Analysis framework for regime level transition.

	Change dimensions	**Present state**	**Short-term change**	**Medium-term change**	**Long-term change**
Regime	Technological				
	Industrial				
	Policy				
	Social				

Table 3c. Analysis framework for niche level transition.

	Change dimensions	**Present state**	**Short-term change**	**Medium-term change**	**Long-term change**
Niche	Technological				
	Industrial				
	Policy				
	Social				

2.6 Interrelations between Sectors in Transition

Furthermore, the interrelations between societal or sectoral systems are likely to mark the major difference in the transition processes. Therefore, the analysis should take into account interrelations between the systems in different sectors (Figure 7). For example, energy generation and distribution systems are likely to be affected by the industrial sectors such as forestry (e.g. in terms of energy demand and use of biofuels) and information and communication technologies (ICT) (e.g. in terms of distributed management of energy production).

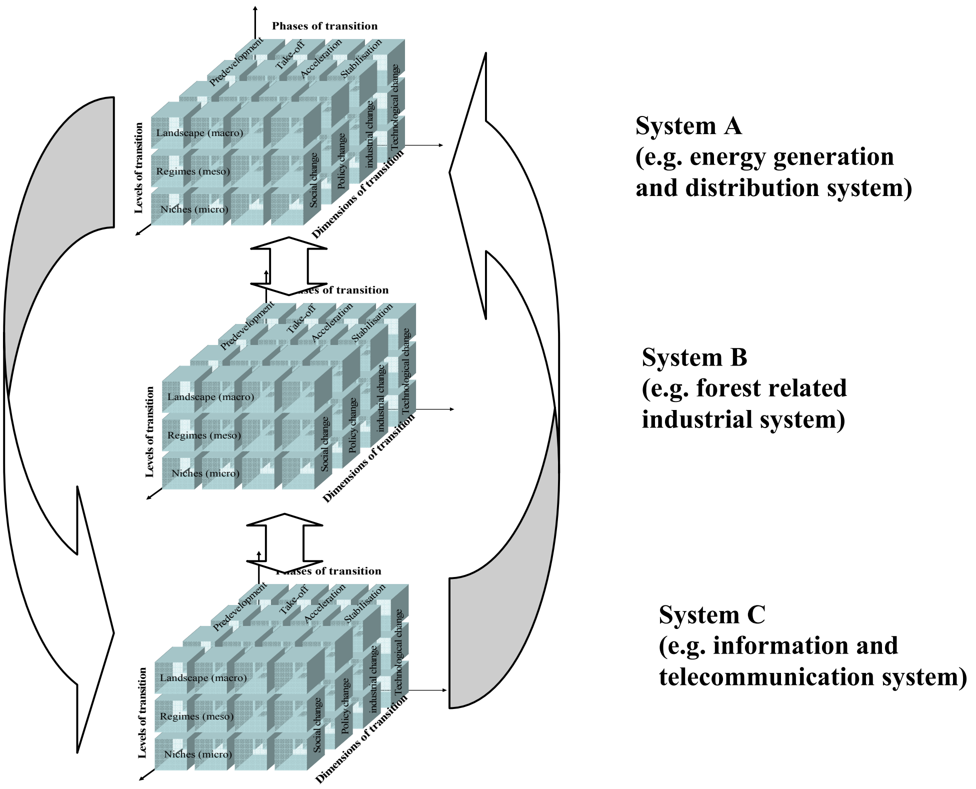

Figure 7. Interrelations between the systems in different sectors.

Alternatively, the inter-relations between systems in different sectors can be illustrated by replacing the dimensions in Figure 5 with different sectors (Figure 8).

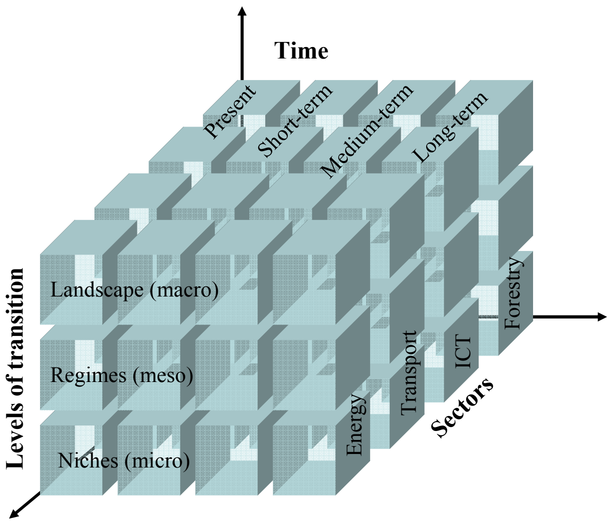

Figure 8. Interrelations between exemplary sectors.

3. Governance of System Transition

3.1 Introduction

This section deals with the governance in system transition. The section explores in particular different options for proactive role of government to initiate and support system transitions. First, different governance approaches are discussed and different functions are identified for the proactive governance of transitions. Later on the governance functions are related to the general framework of system transitions developed in Section 2.

3.2 Combined Approaches in Governance

Tukker and Butter (2007) apply cultural theory (Thompson et al., 1990) to analyse the role of transition management in the governance of sustainable development. According to cultural theory social organisation can be understood in view of the extent to which an individual is bound in a unit (or social group) and in view of the degree to which an individual's life is determined by external prescriptions (rules and norms). These two dimensions can be illustrated as axes that form four approaches[xiii] to social organisation (Figure 9):

- Egalitarian; strong group boundaries with minimal prescriptions.
- Hierarchist; strong group boundaries and strong binding prescriptions.
- Individualist; neither group incorporation nor prescribed role. In this case, all boundaries are provisional and subject to negotiation.
- Fatalist; binding prescription and excluded from group membership.

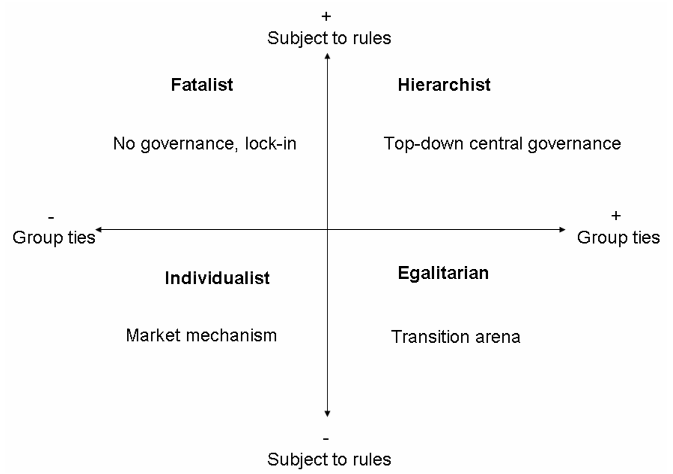

Figure 9. Forms of social organisation and governance styles (modified from Tukker & Butter, 2007).

According to cultural theory, these different forms of social organisation co-evolve in society: there is a positive feedback system that prevents extinction of any of them. In terms of governance of transitions, the challenge is to combine the different approaches in an effective way. Such combined approaches should also address different levels of analysis, including niches, regimes and landscape developments.

On the landscape level, the climate change mitigation efforts can be considered as a representative case on present global governance. Considering the strong reliance on – or even lock-in to – the carbon based energy production many nation states could be claimed to be applying the fatalist approach. On the other hand, the international negotiations of the Post-Kyoto agreement propose proactive approach combining different forms of social organisation. The combination of hierarchist and egalitarian approaches are used to develop suitable market conditions (e.g. emission permits) that would support also individualist approaches.

Alternatively, *in the niche and regime level*, the transition management approach applied in the Netherlands has focused on the egalitarian dimension to improve the communication and coordination within the society. Towards this end, different Transition Arenas have been initiated (see Box 2 on transition arenas).

Box 2. Transition Arenas in the Netherlands

During the last decade or so, general societal ambitions have surfaced in the Dutch society which is embedded in a small but densely populated territory with an advanced economy. These ambitions relate mainly to the problems arising from this situation, such as loss of bio-diversity, over-exploitation of resources, structural risks (such as health risks from the use of non-natural substances, risks of land-flooding in areas located below sea-level), and the like. The solution to these is only to be found in fundamental changes in the underlying systems of production and consumption that have generated wealth for the Dutch over many decades. The realisation of the need to decouple economic growth from harmful degradation grew, implying that deep changes in vital, functional systems required changes in government policy as well. Hence, the government's interest in sustainability transitions grew stronger. The solutions to the societal ambitions required what was labelled "system innovation", which was subsequently adopted by the Dutch policy makers in well-organised efforts to reach higher aspirations. This development has been noted to mark a shift in policy thinking, which used to be preoccupied with upgrading existing functional systems, but were now increasingly seen as being unsustainable as a whole and in need for a more pervasive, structural change. A range of studies were commissioned by the Dutch government which facilitated the learning process of shifting policy thinking. From these, it became clear that changes in the socio-economic system could be facilitated by technology when approached from the wider perspective of more pervasive technological systems. Thus, 'system innovation' and transition were born as a new policy focus besides system improvement.

The Netherlands' government has taken on the ambition to break with the current system for energy supply. The intermediate goal for 2020 is to be one of the most sustainable nations in Europe, and the final goal for 2050 is to have completed the shift to a 100% sustainable energy supply. In order to make the transition, the government has deployed a mega project, involving the entire society called *Energie Transitie* (Energy Transition). In order to concretise such a pervasive project, seven theme-based platforms were established. Market participants, scientific and civil organizations, and government agencies are taking the lead in each of the seven themes.

Analysis by some observers suggests that as of early 2007, somewhat limited success was achieved in those procedures needed to achieve more radical breaks with the present situation in the energy domain.

This is due to the dilemmas that arise from putting system innovation into motion: The transition-approach runs a risk of being 'hijacked' by the incumbent energy regime due to its dominant position, which undermines potential radical innovation in the energy system. Regime actors influence the use of selection criteria for themes, pathways and experiments, thus influencing the direction of variety creation needed to open-up new spaces of renewal. The result is change that is somewhat biased to improvement of the incumbent systems. Furthermore, a dominant position of actors has made it difficult to combine the nurturing of niches with selective pressure on the current energy regime actors, since a risk of losing their engagement arised. However, the design of the transitions approach allows space for a continued debate over energy transition. In all, one could interpret this as a case for the transitions-approach, with the aim to widen and deepen the dialogues in order to restore the intended power-balance that underlies transition-thinking and moving further away from technocratic thinking.

Sources: Loorbach (2007), Kern and Smith (2007), Smith and Kern (2007).

It is likely that the effective approaches to transition governance will need to combine not only the different forms of social organisation but also address these issues in different levels including niches, regimes and landscape developments. In view of the government engagement in the transitions in a proactive role, five governance functions can be identified (see also Table 4 illustrating the possible contents and objectives of these five governance functions):

- Information services, networking, setting common agendas
- Strategic procurement
- Financing research and education
- Grants, equity support and fiscal measures (supply and demand)
- Regulation and standards.

Table 4. Contents and objectives of the five governance functions.

Governance Functions	**Description**	**Objective**	**Examples**
Information services, networking, setting common agendas	Cross-disciplinary, sectoral and regional/national networking Coordination of future plans and actions	Building new collaboration and/or breaking up lock-ins Supporting continuity and predictability (lower risks)	Brokerage Networks Strategic action plans – Information and brokerage – Foresight – Science parks, incubators – Social arenas, platforms – Systemic policies
Strategic procurement, (pre-)market	Occurs when the demand for certain technologies, products or services is encouraged in order to stimulate the market	Create demand and develop markets for innovative solutions	R&D procurement Public procurement of innovative goods Financing demonstration projects as pre-market procurement
Financing research and education	Financing research and education	Develop research and education	University funding R&D and demonstration programmes Contract research
Grants, equity support and fiscal measures (supply and demand)	The use of economic instruments to influence on (perceived) risks and opportunities	Influencing preferences (both short and long-term)	Public venture capital Loss underwriting and guarantees Tax incentives, reductions Subsidies Partnerships Reimbursable loans R&D grants, prices
Regulation and standards	Regulation and voluntary industry standards	Predictability of benefits for first movers; extended and shared responsibility; better performance	Regulations Standards

In practice, the governance tools are likely to cover several functions. For instance, Environmental Voluntary Agreements (EVA) can be combinations of setting common agendas, strategic procurement and standards. EVA are cooperation agreements between industries and/or firms and the agencies responsible for environmental regulation. This may constitute a relatively effective instrument with which to stimulate technological innovation, compared with separate instruments such as taxes, standards or trading permits (Menanteau, 2002; Carraro & Leveque, 1999). Delmas and Terlaak (2001) offer numerous examples of EVA being applied successfully in the international business community.

Another example of the cross-functional governance approach is Strategic Niche Management (SNM), which is a process oriented towards modulating the dynamics of techno-institutional change by creating and managing spaces in which a new technology can be used (Weber et al., 1999). Through this limited temporary protection SNM aims to create a space that is protected from the selective pressures of the market. This strategy is particularly useful in the case of "clean" technologies, in which the social benefits are undervalued by the market, and systemic technologies, such as energy technologies.

The impacts of the described governance functions (Table 4) can be considered in view of transition phases (Table 5). Different phases of the transition are likely to require different kinds of governance with different objectives and tools and engaged stakeholders (Lund, 2007). For instance the governance in the predevelopment and take-off phases needs to focus on the collaboration towards the establishment of development platforms and supporting competition between different platforms. Even though many even radical innovations emerge from regimes, it may be relevant that during the incubation phase the governance efforts foster also activities in which regime advocates (e.g. industrial, policy, RTD, etc.) have limited influence in order to ensure the development of competing alternative pathways and the diversity of technological options. The governance in the acceleration phase is likely to put emphasises on the measures to support the improvements in performance of the system and increasing collaboration with the regime advocates. Finally, in the stabilisation phases, the governance should seek the balance between optimization and system renewal (creating opportunities for the next wave of transition). Possible governance actions in the various phases are illustrated in Table 5.

Table 5. Governance functions and corresponding actions in the various transition phases.

Functions:	**Transition phases:**			
	Predevelopment	**Take-off**	**Acceleration**	**Stabilization**
Information services, networking, setting common agendas	Foster competing networks Competing strategies	Consolidation to few networks Consolidation of strategies	Emergence of the dominant network Emergence of the dominant strategies	Opening, diverging the dominant network Divergence of competing strategies
Strategic procurement, (pre-)market	Pre-market R&D support Demonstration projects	Solution-based lead market formation	Solution-based lead market formation	Performance based procurement
Financing research and education	Pilot infrastructures and training and education for skills, RD&D nodes	Entrepreneurial skills formation		Cost management
Grants, equity support and fiscal measures (supply and demand)	Fostering diversity of viable options (different levels of ambition, engagement according to selected priorities; exchange of information to demonstration) Scientific excellence, quality Awards Credit guarantees Subsidies Vision-based procurement	Supporting convergence among options Priority-setting for quantity, critical mass Awards Credit guarantees Subsidies Solution, technology based procurement Lead market infrastructures, and institutions	Taxes Emission permits Performance based procurement Infrastructural and institutional expansion	Taxes Emission permits Performance based procurement Infrastructure and institution maintenance
Regulation and standards	Alternative enabling standards Regulatory plans Vision based regulation	Dominant standards Regulatory plans Vision based regulation	Dominant standard Regulatory support Top-Runner regulation	Regulating for performance and change

3.3 Governance and Transition Framework

The governance functions discussed in Section 3.2 can be addressed in connection with the transition framework developed in Section 2. This provides overarching framework for the analysis of transition research and governance (Table 6).

Table 6. Transition framework and governance functions.

	Change dimensions	Present state	Short-term cahnge	Medium-term change	Long-term change
Landscape	Technological				
	Industrial				
	Policy				
	Social				
Regime	**Change dimensions**	**Present state**	**Short-term change**	**Medium-term change**	**Long-term change**
	Technological				
	Industrial				
	Policy				
	Social				
Niche	**Change dimensions**	**Present state**	**Short-term change**	**Medium-term change**	**Long-term change**
	Technological				
	Industrial				
	Policy				
	Social				
Governance	**Functions**	**Present state(?)**	**Short-term change**	**Medium-term change**	**Long-term change**
	Information services, networking, setting common agendas				
	Strategic procurement (pre-)market				
	Financing research and education				
	Grants, equity support and fiscal measures (supply and demand)				
	Regulation and standards				

Table 6 can be applied in the analysis of the system transition and the corresponding required governance actions. This approach aims at approaching the governance challenges which means the need to integrate different systems in different phases of transition and their different levels and dimensions.

4. Governance and Research of Energy System Transition

Despite a gradual policy application of transition approaches, especially in the Netherlands (e.g. the Fourth Dutch National Environmental Policy Plan 2001, and recent Transition Platforms) and diverse European research efforts (e.g. BLUEPRINT, 2003), in the Nordic countries there are only emergent research and governance activities explicitly building on transition research and governance. The unfamiliarity and lack of experience in Nordic countries have meant that the use of transition approaches in policy-making and governance has received insufficient attention. Thus, efforts in applying these perspectives for supporting the Nordic actors' proactive participation in the global energy transition have been quite limited or rather loosely coordinated so far.

However, there are plenty of energy research and governance activities that provide the relevant basis for the understanding and developing proactive transition governance approaches. While Nordic efforts have often not been initiated within the mindset of creating system transitions they may hold the promise of relevant seeds for transition governance. Towards this end, the analytical framework developed in this section is meant to be applied as a tool for examining the characteristics of recent and on-going efforts in view of transition governance. Furthermore, the framework should provide relevant starting point to assess how different projects provide overarching understanding of the developments in the energy sector, and what kinds of existing linkages and further synergies can be identified between the projects, e.g. in the Nordic countries. Such analysis may provide a novel approach to understand the Nordic energy research and governance and lead to further coordination of efforts both on the Nordic level as well as European and global level cooperation.

For the didactic purposes, Table 7 provides an illustration how three very different kinds of energy sector research and governance projects can be positioned in the transition framework. The 'Landscape' level in Table 7 refers to developments such as changes in global oil and gas reserves; the 'Regime' level to the established energy production and consumption system in the Nordic countries and the 'Niche' section to emerging new energy production, distribution and consumption solutions that are currently developed and/or demonstrated in the Nordic countries and elsewhere. The two Nordic projects, ESCO Social Embedding and NEP Energy Models and are illustrated together with a Dutch transition management case (Greenhouse Platform). The brief descriptions of the cases are available in Boxes 3, 4 and 5.

Table 7. Examples of governance and research for energy transition in practice. Illustrating the conceptual framework as a tool for positioning research and governance projects that are intended to support the energy system transition.

<table>
<tr><td rowspan="5">**Landscape**</td><td></td><td>**Present**</td><td>**Short-term**</td><td>**Medium-term**</td><td>**Long-term**</td></tr>
<tr><td>*Technological*</td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Industrial*</td><td></td><td colspan="3">Nordic Energy Scenarios</td></tr>
<tr><td>*Policy*</td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Social*</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">**Regime**</td><td></td><td>**Present**</td><td>**Short-term**</td><td>**Medium-term**</td><td>**Long-term**</td></tr>
<tr><td>*Technological*</td><td colspan="4">Greenhouse Platform</td></tr>
<tr><td>*Industrial*</td><td colspan="4">NEP Energy Models</td></tr>
<tr><td>*Policy*</td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Social*</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">**Niche**</td><td></td><td>**Present**</td><td>**Short-term**</td><td>**Medium-term**</td><td>**Long-term**</td></tr>
<tr><td>*Technological*</td><td colspan="4">Greenhouse Platform</td></tr>
<tr><td>*Industrial*</td><td colspan="3">ESCO Social Embedding</td><td></td></tr>
<tr><td>*Policy*</td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Social*</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="8">**Governance**</td><td></td><td>**Present**</td><td>**Short-term**</td><td>**Medium-term**</td><td>**Long-term**</td></tr>
<tr><td rowspan="3">*Information services, networking, setting common agendas*</td><td colspan="4">Nordic Energy Scenarios</td></tr>
<tr><td colspan="4">Greenhouse Platform</td></tr>
<tr><td colspan="3">ESCO Social</td><td></td></tr>
<tr><td>*Strategic procurement, pre-market*</td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Financing research and education*</td><td colspan="3">Greenhouse Platform</td><td></td></tr>
<tr><td>*Grants, equity support and fiscal measures (supply and demand)*</td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Regulation and standards*</td><td></td><td></td><td></td><td></td></tr>
</table>

Box 3. Societal Embedding of ESCO Energy Saving Concept

The ESCO concept is based on the idea that ESCOs (Energy Service Companies) offer their customers the service of taking the responsibility for implementation of energy saving investments by financing, designing and installing the equipment, and gain their returns by taking a share of the energy costs saved. As to the societal embedding, it can be characterised as an interactive learning process among producers, users and various societal actors. The innovation is shaped in co-operation to fit the needs of the market. In this case, the positive development is a consequence of successful local experimentation and landscape developments that have put pressure on regime level changes. The societal embedding approach needs to be further developed, but to be an effective tool in transition it must be supported by other policy instruments such as legislation and financial incentives. (Kivisaari et al., 2003.)

Box 4. NEP Energy Models

Nordic Energy Perspectives (NEP) is an interdisciplinary Nordic energy research project (2005–2010). NEP project has been a good example of the positive impacts of modelling exercises to increase understanding and to promote discussion between different interest groups within the energy sector. International cooperation between modellers has also proved to be essential to make the models more sophisticated to enhance the understanding of local conditions and modelling traditions.

Two Nordic energy system model (MARKAL Nordic & Balmorel), three Nordic electricity market models (ECON Classic, VTT EMM, PoMo), one national macroeconomic (Finnish GTAP) model demonstrated the wide variety of approaches used in Nordic decision making nationally. During the second phase of the NEP, the "modelling tool box" was enlarged with two global models, i.e. global macroeconomic (GTAP) model and global energy system model (Global ETSAP TIAM), to give a wider perspective of political decision making on Nordic economies and Nordic energy systems. An important result has been that even the models with the same mathematical approach and the same exogenous input data, the results could differ considerably. On the other hand, different Nordic countries seem to use different types of models for the same questions (e.g. for the background analysis of the energy and climate policies including supporting schemes, taxation, etc.). The more specific Nordic electricity market models and the traditional bottom-up energy system models for Nordic area could be also required to include more detailed analysis with local conditions.

Box 5. Greenhouse Platform in the Netherlands[xiv]

One thematic platform of the Energy Transition program of the Netherlands' government is the *'Greenhouse as Energy Source' Platform*. The Dutch greenhouse horticulture sector has set the objective for 2020 that newly constructed greenhouses should be practically independent from fossil energy, and the sector as a whole should have a strongly reduced dependence. The Platform stimulates research on renewable energy in greenhouse horticulture and supports innovative developments in horticultural practice. Represented parties in the platform are: the Horticultural Commodity Board, LTO Glaskracht Nederland (the association of entrepreneurs in the sector), the ministries of Agriculture, Economic Affairs, and Environment, Wageningen UR (the agricultural university's research centre), VGB (the association of wholesale traders in horticultural products), Gasunie (natural gas-infrastructure company), Stichting Natuur en Milieu (a nature conservationist organisation), and Priva as representative from the horticultural supply chain. The aim has been set for 2020 to achieve: Climate-neutral (new estate) greenhouses; 30% less CO_2 emissions; To be a *supplier* of sustainable heat and energy; strongly reduce use of fossil energy. The Platform's means to reach its goals are formulated in seven 'transition paths' evolving around: Solar energy; Geothermal energy; Biofuels; Growing strategies and low-energy varieties; Intelligent use of Light; Renewable electricity; and Reuse of CO_2.

The positioning of these three energy sector projects in the developed framework provides a simplistic illustration and a starting point of its possible application; how more comprehensive and in-depth analysis of recent and on-going research and governance efforts could be conducted to provide further basis to identify relevant synergies and areas for future developments. Moreover, this overarching transition framework may be applied to support the coordination efforts between many, sometimes even controversial, governance efforts in the development of the energy system. Application of the framework is also included in the subsequent GoReNEST tasks with the aim of

- testing the feasibility of the conceptual framework
- positioning and analysing the recent Nordic research activities that are intended to contribute to the policies and governance of energy system transition
- positioning and analysing the governance and funding models and practices that are intended to contribute to the energy system transition
- refining and elaborating the conceptual framework on the basis of the 'lessons learned'.

5. Conclusions and Further Steps

System transitions are complex societal co-evolutionary processes that are typically led by gradual adaptation rather than visionary management or coordination. Indeed, several authors have argued that, especially in the energy sector, desired transitions are difficult to initiate and achieve, because the prevailing system acts as a barrier to the creation of a new system. Still, visionary coordination of policies, regulation, corporate strategies and social learning may overcome some barriers and foster new innovation efforts providing sufficient impetus towards system transition.

Building on earlier literature and experiences on system transitions and related research and governance, this paper develops an analytical framework. This framework integrates different transitions phases, levels and dimensions and combines them with the governance functions to provide overarching frames for understanding system transitions. While the framework is developed keeping in mind its application in the Nordic energy system transition research and governance, it may also be applicable in other sectors. Indeed, the improved understanding of the system transition is likely to require cross-sectoral horizontal analysis as much as the vertical multi-level analysis of niches, regimes and landscapes.

For the didactic purposes, the paper applies the framework in the analysis of the three energy sector projects by positioning them in the developed framework. More comprehensive and in-depth analysis of recent and on-going research and governance efforts may provide further basis to identify relevant synergies and areas for future developments. Moreover, the use of such overarching transition framework supports the coordination efforts between many sometimes even controversial efforts in the development of energy systems.

The conceptual framework presented in this working paper is intended to provide a preliminary tool that enables a more conscious and manageable energy system transition in the Nordic countries, paying also attention to the global transition and utilization of new business opportunities in the Nordic countries. The conceptual framework is applied and elaborated in the subsequent tasks of the GoReNEST project. In Task 2, the framework is applied and elaborated in the analysis of Nordic energy research activities. In particular, research activities that are intended to support the energy and climate policy and the governance of the energy system transition in the Nordic countries are in the focus of further efforts. In Task 3, the framework is applied and elaborated in the analysis of governance and funding models and practices that can be applied to innovative energy programs and initiatives in order to support system transition. In Task 4, the framework is used as a communication tool among Nordic energy sector stakeholders to communicate the issues related to system transitions. In Task 5, the framework is fine-tuned and included in the final report of the project.

Acknowledgements

The authors are grateful for the comments and supporting materials to their colleagues in VTT Technical Research Centre of Finland, in particular, to Annele Eerola, Torsti Loikkanen, Tiina Koljonen and Nina Wessberg. Furthermore, this research has been possible due to financial support received from the Nordic Energy Research and VTT Technical Research Centre of Finland.

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i Könnölä and Unruh (2006) define *continuity* type changes as incremental competence enhancing modifications that preserve existing systems and sustain the existing value networks in which technologies are rooted. *Discontinuity* type changes, in contrast, are competence destroying, radical changes that seek the replacement of existing components – or entire systems – and the creation of new value networks. Distinguishing between the two can be complicated, however, by the fact that what is discontinuous at one level of analysis may appear continuous at a higher level of analysis (Unruh, 2002). The shift from hard disk drives to flash memory, for example, can be discontinuous for disk drive manufactures, but continuous for the larger personal computer value network in which memory is an embedded component.

ii *Innovation* is a systemic change process of (physical) technologies and institutions, which consists of both the elements of the invention of an idea for change and its application and diffusion in practice.

iii The term 'transition' was originally used to describe a non-linear rather chaotic shift process of the phases of substances from solid, to liquid to gas, and later on it has been applied in many fields, including institutional and technological studies.

iv On precise definitions of knowledge, see Metcalfe (1995).

v Indeed, Nelson and Sampat (2001) as well as North (1990) have posited that the co-evolutionary features identified as creating increasing returns for physical technologies may also be applied to institutions as social technologies.

vi Evolutionary economists apart from the way in which the (aggregate) production function is used by neoclassical economists and their apparent neglect of explaining the processes of technological change (Nelson & Winter, 1974, 1977, 1982, 2002; Dosi, 1982; Dosi et al., 1988). The evolutionary approach utilises insights and models from evolutionary biology to explain the dynamics of economic phenomena. Thus, while the neoclassical approach portrays technological change as a simple change in the information available on the relationship between the economy's inputs and outputs (Stoneman, 1983; Gomulka, 1990), the evolutionary approach considers technological change to be the result of a process of evolution, influenced by the prevailing economic, social and political institutions.

vii *Selection* refers to the process that instead reduces variety and gives direction to development. In a broad sense, here we can think of a host of processes that occur on micro and macro levels, such as competition, imitation, legislation or even recessions and environmental disasters. Besides on various levels, selection also has different dimensions, such as science (e.g. thermo-dynamic limits), technology (what is possible), markets (products, financial, labour), geography, organisational (e.g. processes in enterprises), institutions and public policy. It is important to note that selection is not stable and as given, nor does it lead to selection of the best options. Rather, a range of 'sufficiently tolerable' options tend to survive selection.

viii While the debate on the validity of the historical ex post cases continues (David, 1985, 1989; Arthur, 1989, 1994; Liebowitz & Margolis, 1995; Mahoney, 2000), the main value of the concept of path dependence is rather in the identification of the mechanisms of path dependence at the different levels of innovation systems.

ix Also many other terms such as ‘socio-technological transformation’ (Geels, 2002) and ‘system innovation’ (Edqvist, 1997) have been used to describe similar kind of fundamental transformation processes of the co-evolution of technological and institutional systems. Several authors have argued that such transitions are difficult to achieve, because the prevailing system acts as a barrier to the creation of a new system (e.g. Arthur, 1989; Kemp & Soete, 1992; Jacobsson & Johnson, 2000; Unruh, 2000, 2002; Kline, 2001; Geels, 2002; Carlsson & Jacobsson, 2004; Frenken et al., 2004; Foxon et al., in press).

x Within Neo Keynesian economics a whole sub-field has grown up dedicated to coordination failures based on the work of Bryant (1983), Diamond (1982), Hart (1982) and Weitzman (1982). According to this literature, in numerous socio-economic situations coordination problems (failures) appear, which can arise from a situation in which there are multiple equilibria (Cooper & John, 1988; Ball & Romer, 1991). These situations include the presence of increasing returns (Weitzman, 1982; Manning, 1990; Bohn & Gorton, 1993). These failures are the result of the inability of the agents to coordinate their actions successfully in a decentralized economy (Cooper & John, 1988: 442). Coordination failure models generate outcomes that are inferior in terms of welfare, due to the fact that the agents have no incentive to change their behaviour and reach a more preferred state of welfare (Allen & Stone, 2001). If the coordination problems reflect the inability of the agents to select the Pareto optimal equilibrium, then the State can take steps to achieve the desired outcome by eliminating some undesirable equilibria as it converts the strategies that support them into dominated strategies (Cooper, 1999: 126).

xi In line with the s-curve approach, Hughes (1987) reports alternatively seven (overlapping and backtracking) phases in the history of evolving systems: 1) invention, 2) development, 3) innovation, 4) transfer, 5) growth, 6) competition, and 7) consolidation. Although seemingly linear, these phases are seen as occurring cyclically. Moreover, the type of prominent actors in system building varies across these phases. An important role is played by inventive-entrepreneurs during the first phases.

xii See also Loch and Huberman (1999: 12); Windrum and Birchenhall (2000: 12); Frenken and Verbart (1998).

xiii Fifth possible way of social organisation would by the solitary person who escapes from coercive or manipulative social involvement altogether.

xiv http://www.kasalsenergiebron.nl/.

http://www.senternovem.nl/energietransitie/.

http://www.senternovem.nl/energytransition/themes/the_greenhouse_as_energy_source_platform/index.asp.

ISBN 978-951-38-7160-4 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN 1459-7683 (URL: http://www.vtt.fi/publications/index.jsp)