System Transition
Concepts and Framework
for Analysing Energy System Research and Governance

IE Working Paper EC8-117-I 10-12-2008

Totti Könnölä [1], Javier Carrillo-Hermosilla [2] & Robert van der Have [3]

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. This paper addresses 'system transition' as a valuable perspective and develops a framework for analysing Nordic energy system research and governance. The framework integrates different transitions phases, levels and dimensions and combines them with the governance functions to provide overarching frames for understanding system transitions. The framework for transition research and governance is applied in the analysis of the energy governance cases and discussed in view of energy system transitions. This paper is based on an extensive literature review and empirically based-theory building.

Key Words

Energy system transition, Innovation, Transition management, Techno-institutional change.

[1]IE Business School, Castellón de la Plana 8, Madrid 28006, Spain, totti.konnola@ie.edu, +34658321050
[2]IE Business School, Castellón de la Plana 8, Madrid 28006, Spain, javier.carrillo@ie.edu
[3]VTT Technical Research Centre of Finland, Group for Innovation Studies robert.vanderhave@vtt.fi

Contents

1. Introduction

The energy 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 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 especially 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.

2. Framework for 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. Building on earlier literature, we develop a general framework for the research of system 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.

2.1 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 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.

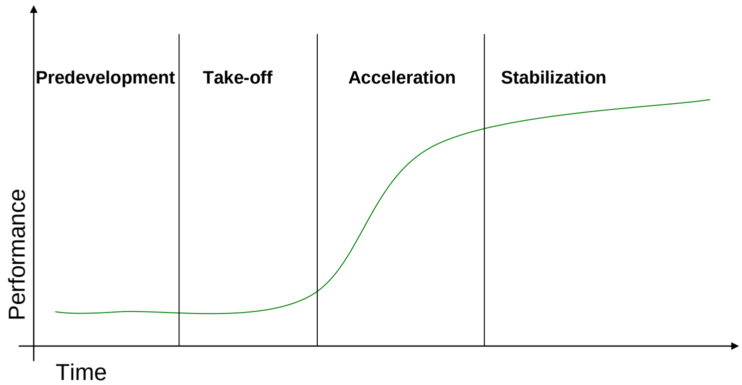


Figure 1. The S-curve and the phases of transition.

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

2.2 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 characteristic is the chosen level of analysis, together with the definition of the regime, so as 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 additional 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.

2.3 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 an increasing number of users adapt to the system, their expectations adapt 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.

2.4 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 2).

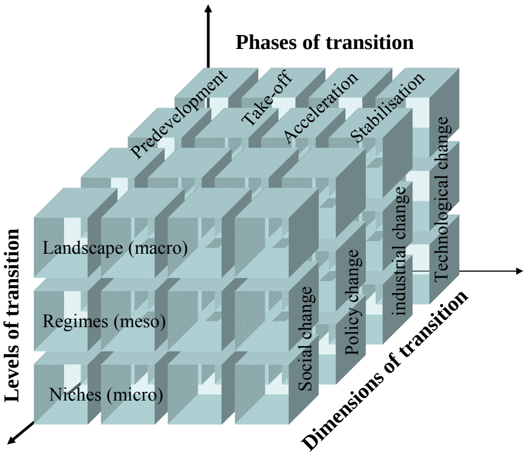


Figure 2. Phases, levels and dimensions of transition.

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 3).

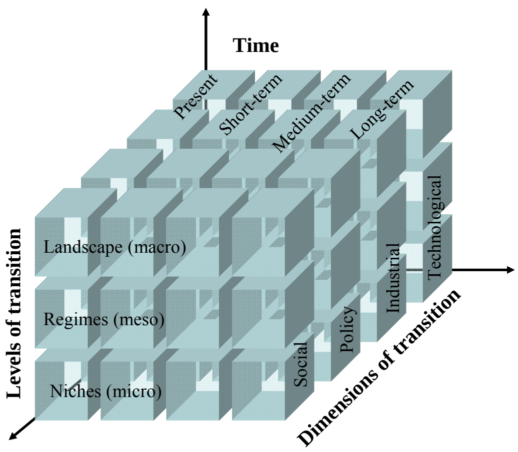


Figure 3. Time, levels and dimensions of transition.

The framework illustrated in Figure 3 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.

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

Table 3b. Analysis framework for regime level transition.

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

Table 3c. Analysis framework for niche level transition.

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

2.5 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 4). 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).

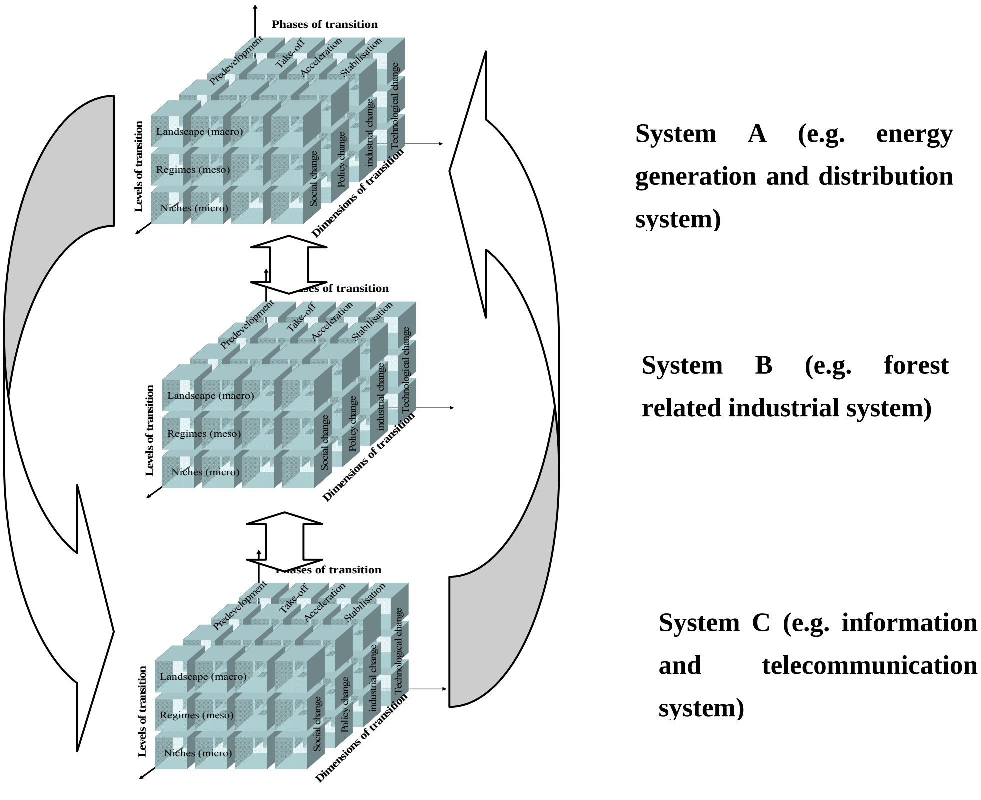


Figure 4. Interrelations between the systems in different sectors.

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 a 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

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	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	Supporting convergence among options Priority-setting for quantity, critical mass Awards Credit guarantees Subsidies Solution, technology based procurement Lead market	Taxes Emission permits Performance based procurement Infrastructural and institutional expansion	Taxes Emission permits Performance based procurement Infrastructure and institution maintenance

	Vision-based procurement	infrastructures, and institutions		
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	Medium-term	Long-term change
Landscape	Technological				
	Industrial				
	Policy				
	Social				
Regime	**Change dimensions**	**Present state**	**Short-term**	**Medium-term**	**Long-term change**
	Technological				
	Industrial				
	Policy				
	Social				
Niche	**Change dimensions**	**Present state**	**Short-term**	**Medium-term**	**Long-term change**
	Technological				
	Industrial				
	Policy				

	Social				
Governance	**Functions**	**Present state(?)**	**Short-term**	**Medium-term**	**Long-term change**
	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 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.

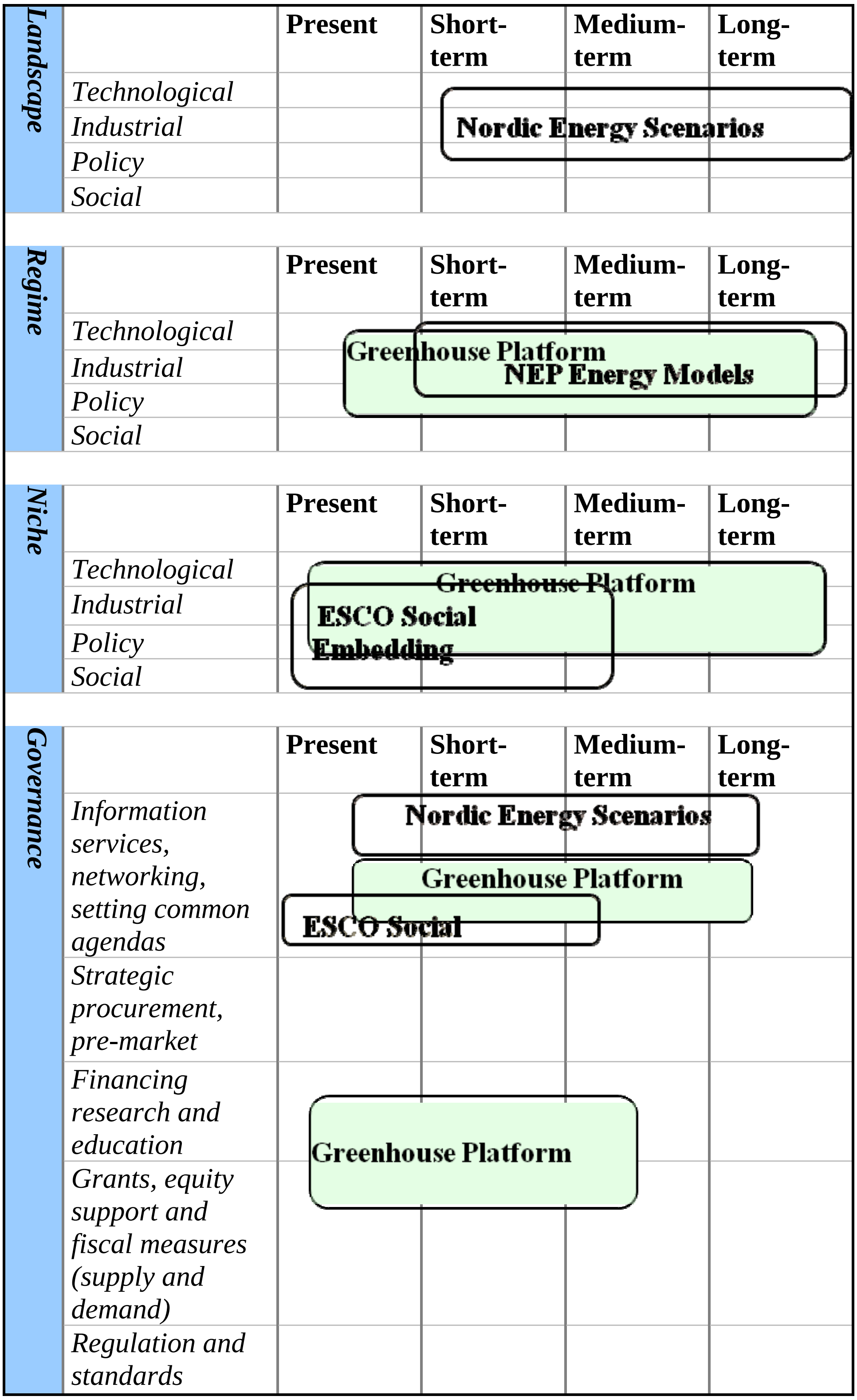
4. Governance and Research of Energy System Transition

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 1, 2 and 3.

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.



Box 1 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 2 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 3 Greenhouse Platform in the Netherlands[xiii]

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.

5. Conclusions

The developed 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.

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.

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.

References

Allen, R.C. and Stone, J.H. (2001). Strategic behavior, real rigidities, and production coordination failures. Eastern Economic Journal, 27(3), pp. 267-286.

Anderson, P. & Tushman, M.L. (1990) Technological discontinuities and dominant designs: A cyclical model of technological change. Administrative Science Quarterly, Vol. 35, pp. 604–633.

Arrow, K.J. (1962a) Economic welfare and the allocation of resources for invention. In: Nelson, R. (ed.) The Rate and Direction of Inventive Activity. Princeton: Princeton University Press. Pp. 609–625.

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

Arthur, B. (1994) Increasing Returns and Path Dependence in the Economy. Ann Arbor: University of Michigan Press.

Arthur, W.B. (1991) Information constriction and information contagion. Working Paper, 91-05-026. Santa Fe: Santa Fe Institute.

Arthur, W.B. 1989, Competing Technologies, Increasing Returns, and Lock-In by Historical Events, The Economic Journal, Vol. 99, No. 394. (Mar., 1989), pp. 116-131.

Ball, L. & Romer, D. (1991) Sticky prices as coordination failure. American Economic Review, Vol. 81, pp. 539–552.

Blackman, A. (1999) The economics of technology diffusion: Implications for climate policy in developing countries. Discussion Paper 99-42. Washington, DC: Resources for the Future.

BLUEPRINT (2003) Blueprints for an Integration of Science, Technology and Environmental Policy. STRATA Project, Contract Nr.: HPV1-CT-2001-00003. Online: http://www.blueprint-network.net/.

Bryant, J. (1983). A simple rational-expectations Keynes-type model. The Quarterly Journal of Economics, August, pp. 25-29.

Bessant, J. and Tidd, J. (2007) Innovation and Entrepreneurship. John Wiley & Sons: Chichester, U.K.

Bohn, H. and Gorton, G. (1993) Coordination failure, multiple equilibria and economic institutions. Economica, August, pp. 257-280.

Carlsson, B. and Jacobsson, S., 2004, Dynamics of Innovation Systems: Policy-making in a Complex and Non-deterministic World. International Workshop on Functions of Innovation Systems, Utrecht University.

Carraro, C. & Leveque, F. (eds.) (1999) Voluntary Approaches in Environmental Policy. Fondazione Eni Enrico Mattei Series on Economics. Energy and Environment. Vol. 14. Dordrecht, Boston and London: Kluwer Academic.

Cooper, R. & John, A. (1988) Coordinating coordination failures in Keynesian models. The Quarterly Journal of Economics, Vol. CIII, Issue 3, pp. 441–463.

Cooper, R.W. (1999) Coordination Games: Complementarities and Macroeconomics. Cambridge: Cambridge University Press.

David, P.A. (1985) Clio and the Economics of QUERTY. American Economic Review, Vol. 75, No. 2, pp. 332–337.

David, P.A. (1989) Path dependence and predictability in dynamic systems with local network externalities: A paradigm for historical economics. High Technology Impact Program Working Paper. Stanford: Center for Economic Policy Research, Stanford University.

Delmas, M. & Terlaak, A. (2001) A framework for analysing environmental voluntary agreements. California Management Review, Vol. 43, No. 3, pp. 44–63.

Diamond, P. (1982) Aggregate demand management in search equilibrium. Journal of Political Economy, October, pp. 881-894.

Dosi, G. (1982) Technological paradigms and technological trajectories. Research Policy, Vol. 11, pp. 147–162.

Dosi, G., Freeman, C., Nelson, R., Silverberg, G. & Soete, L. (eds.) (1988) Technical Change and Economic Theory. London: Pinter.

Economides, N. (1996) The economics of networks. International Journal of Industrial Organization, Vol. 14, Issue 6, pp. 673–699.

Edqvist, C. (ed.) (1997) Systems Innovation: Technologies, Institutions and Organisations. London: Pinter Publishers.

Fagerberg, J. (2003) Schumpeter and the Revival of Evolutionary Economics: an Appraisal of the Literature. Journal of Evolutionary Economics, Vol. 13, pp. 125–159.

Farrell, J. & Saloner, G. (1986a) Installed base and compatibility: Innovation, product preannouncements, and predation. The American Economic Review, Vol. 76, No. 5, pp. 940–955.

Farrell, J. & Saloner, G. (1986b) Standardization and Variety. Economic Letters, Vol. 20, pp. 71–74.

Foster, R.N. (1986) Innovation: The Attacker's Advantage. London: MacMillan.

Foxon, T.J., Gross, R. et al. (in press) UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy.

Frenken, K., Hekkert, M. & Godfroij, P. (2004) R&D Portfolios in Environmental Friendly Automotive Propulsion: Variety, Competition and Policy Implications. Technological Forecasting and Social Change, Vol. 71, No. 5, pp. 485–507.

Frenken, K. & Verbart, O. (1998) Simulating paradigm shifts using a lock-in model. In: Ahrweiler, P. & Gilbert, N. (eds.) Computer Simulation in Science and Technology Studies. Berlin: Springer-Verlag.

Geels, F. (2006). Major system change through stepwise reconfiguration: A multi-level analysis of the transformation of American factory production (1850–1930), Technology in Society 28 (2006) 445–476.

Geels, F.W. (2002) Technological transitions as evolutionary reconfiguration processes: a multilevel perspective and a case-study. Research Policy, Vol. 31, No. 8–9, pp. 1257–1274.

Gomulka, S. (1990) The Theory of Technological Change and Economic Growth. London: Pinter Publishers.

Hart, O. (1982) A model of imperfect competition with Keynesian features. Quarterly Journal of Economics, February, pp. 109–138.

Holtz, G., Brugnach, M. and Pahl-Wostl, P., in press. Specifying "regime" — A framework for defining and describing regimes in transition research. Technological Forecasting & Social Change.

Hughes, T.P. (1987) The evolution of large technological systems. In: Bijker, W.E., Hughes, T.P. & Pinch, T. (eds.) The social construction of technological systems. New directions in the sociology and history of technology. Cambridge, MA: MIT Press. Pp. 51–82.

Jacobsson, S. & Johnson, A. (2000) The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research. Energy Policy, Vol. 28, pp. 625–640.

Katz, M.L. & Shapiro, C. (1985) Network externalities, competition and compatibility. The American Economic Review, Vol. 75, No. 3, pp. 424–440.

Katz, M.L. & Shapiro, C. (1986a) Product compatibility choice in a market with technological progress. Oxford Economic Papers, Vol. 38 (Supplement), pp. 146–165.

Katz, M.L. & Shapiro, C. (1986b) Technology adoption in the presence of network externalities. Journal of Political Economy, Vol. 94, No. 4, pp. 822–841.

Kemp, R. & Soete, L. (1992) The greening of technological progress: An evolutionary perspective. Futures, June, pp. 437–455.

Kivisaari, S., Lovio, R. & Väyrynen, E. (2004) Managing experiments for transition: Examples of societal embedding in energy and health care sectors. In: Elzen, B., Geels, F.W. & Green, K. (eds.) System Innovation and the Transition to Sustainability. Cheltenham, UK: Edward Elgar.

Kivisaari, S., Lovio, R. & Väyrynen, E. (2003) The Role of Local Experiments in Transition to Sustainability: The Case of Societal Embedding of ESCO energy saving concept. Paper presented at the 2003 Greening of Industry Conference, 12–15 October, San Francisco, USA. Available in PDF at http://gin.confex.com/gin/2003/techprogram/P3.HTM.

Kline, D. (2001) Positive Feedback, Lock-in, and Environmental Policy. Policy Sciences, Vol. 34, pp. 95–107.

Könnölä, T. & Unruh, G.C. (2006) Really Changing the Course: The Limitations of Environmental Management Systems for Innovation. The Journal of Business Strategy and the Environment, Vol. 16, No. 8, pp. 525–537.

Könnölä, T. (2007) Industry Dynamics and Technological Roadmaps in International RD&D Management. Knowledge for Growth: Role and Dynamics of Corporate R&D. First European Conference, IPTS Joint Research Centre of European Commission, Seville, Spain, October 8th – 9th 2007. http://iri.jrc.es/concord-2007/papers/strand6/Konnola.pdf.

Kemp, R., Schot, J. & 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, No. 2, pp. 175–197.

Kern, F. & Smith, A. (2007) Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. Sussex Energy Group Working Paper.

Laffond, G., Lesourne, J. & Moreau, F. (1999) Interaction between public policies and technological competition under environmental risks. In: Cartner, U., Hanusch, H. & Klepper, S. (eds.) Economic Evolution, Learning and Complexity. Heilderberg: Springer Verlag. Pp. 287–312.

Liebowitz, S.J. & Margolis, S.E. (1995) Path Dependence, Lock-in and History. Journal of Law and Economics, Vol. 33, pp. 1–25.

Llerena, P. & Matt, M. (1999) Inter-organizational collaborations: The theories and their policy implications. In: Gambardella, A. & Malerba, F. (eds.) The Organization of Economic Innovation in Europe. Cambridge: Cambridge University Press. Pp. 179–201.

Loch, C.H. & Huberman, B.A. (1999) A punctuated-equilibrium model of technology diffusion. Management Science, Vol. 45, No. 2, pp. 160–177.

Loorbach, D. (2007) Transition Management – New mode of governance for sustainable development. Utrecht, the Netherlands: International Books.

Lund, P.D. (2007) Integrated European Energy RTD as Part of the Innovation Chain to Enhance Renewable Energy Market Breakthrough. In: Sønderberg Petersen, L. & Larsen, H. (eds.) Energy Solutions for Sustainable Development. Proceedings of Risø International Energy Conference, Risø-R-1608(EN).

Mahoney, J. (2000) Path Dependence in Historical Sociology. Theory and Society, Vol. 29, pp. 507–548.

Manning, A. (1990) Imperfect competition, multiple equilibria and unemployment policy. The Economic Journal, Vol. 100, Issue 400, pp. 151–162.

Menanteau, P. (2002) Can negotiated agreements replace efficiency standards as an instrument for transforming the electrical appliance market. Cahier de Recherche N° 28 BIS, Institut d'Economie et de Politique de l'Energie.

Metcalfe, J.S. (1995) Technology systems and technology policy in an evolutionary framework. Cambridge Journal of Economics, Vol. 19, No. 1, pp. 25–46.

Moreau, F. (1999) The role of the State in an Evolutionary Microeconomics. Working Paper du Laboratoire d´Econométrie, nº99-1. Paris: Conservatoire National des Arts et Métiers.

Mowery, D. & Rosenberg, N. (1989) New developments in US technology policy: Implications for competitiveness and international trade policy. California Management Review, Vol. 32, pp. 107–124.

Nelson, R. & Sampat, B. (2001) Making Sense of Institutions as a Factor Shaping Economic Performance. Journal of Economic Behaviour and Organization, Vol. 44, Issue 1, pp. 31–54.

Nelson, R.R. (1994) The coevolution of technologies and institutions. In: England, R.W. (ed.) Evolutionary Concepts in Contemporary Economics. Ann Arbor: University of Michigan.

Nelson, R.R. & Winter, S.G. (1974) Neo-classical vs. Evolutionary theories of economic growth. Economic Journal, Vol. 84, pp. 886–905.

Nelson, R.R. & Winter, S.G. (1977) In search of useful theory of innovation. Research Policy, Vol. 6, pp. 36–37.

Nelson, R.R. & Winter, S.G. (1982) An Evolutionary Theory of Economic Change. Cambridge, MA: The Belknap Press of Harvard University Press.

Nelson, R.R. & Winter, S.G. (2002) Evolutionary Theorizing in Economics. Journal of Economic Perspectives, Vol. 16, No. 2, pp. 23–46.

North, D. (1990) Institutions, Institutional Change and Economic Performance. Cambridge, UK: Cambridge University Press.

Porter, M.E. (1990) The Competitive Advantage of Nations. London: MacMillan.

Porter, M.E. (1998) Clusters and the new economics of competition. Harvard Business Review, Nov.–Dec. 1998.

Powell, W. & DiMaggio, P. (eds.) (1991) The New Institutionalism in Organizational Analysis. Chicago, IL: The University of Chicago Press.

Rotmans, J., Kemp, R., et al. (2001) More evolution than revolution: transition management in public policy. Foresight: the journal of futures studies, strategic thinking and policy, Vol. 3, No. 1, pp. 15–32.

Sheshinski, E. (1967) Optimal accumulation with learning by doing. In: Shell, K. (ed.) Essays on the Theory of Optimal Economic Growth. Cambridge, MA: MIT Press. Pp. 31–52.

Simon, H.A. (1959) Theories of Decision Making in Economics. American Economic Review, Vol. 49, pp. 253–283.

Simon, H.A. (1965) Administrative Behaviour. 2nd ed. New York: Free Press.

Smith, A. & Kern, F. (2007) The transitions discourse in the ecological modernization of the Netherlands. SPRU Working Paper. May 2007.

Stoneman, P. (1983) The Economic Analysis of Technological Change. New York Strategic Management, Vol. 10, No. 2, pp. 175–195.

Thompson, M., Ellis, R. & Wildavsky, A. (1990) Cultural theory. Boulder, CO, USA: Westview Press.

Tukker, A. & Butter, M. (2007) Governance of sustainable transitions: about the 4(0) ways to change the world. Journal of Cleaner Production, Vol. 15, pp. 94–103.

Unruh, G.C. (2002) Escaping Carbon Lockin. Energy Policy, Vol. 30, pp. 317–325.

Unruh, G.C. (2000) Understanding Carbon Lockin. Energy Policy, Vol. 28, pp. 817–830.

Weber, M., Hoogma, R., Lane, B. & Schot, J. (1999) Experimenting with sustainable transport innovations: A workbook for strategic niche management. IPTS Report. ISBN 9036512751.

Weitzman, M. (1982) Increasing Returns and the Foundations of Unemployment Theory. Economic Journal, December 1982, pp. 787–804.

Windrum, P. & Birchenhall, C. (2000) Modelling technological successions in E-Commerce. MERIT/Infonomics. Maastricht: University of Maastricht.

[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] 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.

[xiii] http://www.kasalsenergiebron.nl/.

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

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