Investigating applicability of innovation system concept[s] in transforming the energy system

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Abstract

The energy system encompasses technical, economical as well as social aspects. Therefore its transformation initially requires and eventually brings, change in the whole socio-technical paradigm. This change covers a wide range of stakeholders, either directly or indirectly, including house-hold consumers, industry (as producer and user), and knowledge producing institutes. It will cause the emergence of new industries and companies, new ways of deliverance, new options and threats. It will require trust and confidence building activities, new investments and opportunities involving emergence of new products and processes, regional and international collaboration in various capacities, supporting market niches and early adopters, close collaboration with the users for testing compatibility, laws, regulations, etc.

Innovation system concept provides us framework to address issues of this scale and diversity. Henceforth, the focus of this paper is to investigate the relevance and applicability of the Innovation System concept in transforming the energy system. It describes essentials of the innovation system concept before, comparing national, sectoral, regional and technology-oriented innovation systems and evaluating them on their relevance to energy sectors. Further more, 'functions of innovation system' along 'phases' as defined by 'multi-phase' concept of 'transition theory' have been used to evaluate the applicability of the concept along transformation process.

Introduction

Presently, available and prevailed energy generation systems are mostly based on resources from fossil fuel, hydro, nuclear and from combustible biomass like wood. Now with the increase in GHG levels in earth's atmosphere because of the continuous and ever increasing use of fossil fuels, phasing out of nuclear power generation, and limits on hydroelectric generation in future, all due to severe, ecological concerns and sustainability issues and intensifying future energy demands, seriously require to seek for transforming the present energy system towards more sustainable one.

The energy system encompasses technical, economical as well as social aspects. Therefore its transformation initially requires and eventually brings, change in the whole socio-technical paradigm. This change covers a wide range of stakeholders, either directly or indirectly, including house-hold consumers, industry (as producer and user), and knowledge producing institutes. It will eventually lead to the emergence of new industries and companies, new ways of deliverance, new options and threats. It will require trust and confidence building activities, new investments and opportunities involving emergence of new products and processes, regional and international collaboration in various capacities, supporting market niches and early adopters, close collaboration with the users for testing compatibility, laws, regulations, etc.

Change on this scale truly requires and demands interventions from particular governments concerned, in various roles and capacities over time. Government's planning and policies are in fact vital to initiate thinking on technically and socially acceptable system innovations for transforming the energy system. Whereas, transforming the energy system is cost-intensive, involves direct public concerns and relates to the national economy as a whole, This calls for government's support not only as a provider of infrastructures and subsidies but also to enhance its role in different institutional capacity building programs and policies i.e., to provide public-private partnerships, to build specific knowledge bodies, to guide and examine the process over time, to facilitate national/international collaborations, to help removing lock-ins in present technology system and also in emerging developments, to support "creative destruction" for new energy system to replace old one, to co-ordinate public awareness programs, to provide support for further innovations in a newly developed system until it matures, etc.

However, energy systems are complex socio-technical systems of production and consumption that include very different subsystems that are extremely complex in it, such as the mobility system, the electricity system, industrial production, as well as heating, lighting and cooling in private homes, offices and other buildings. A further complication is that transforming energy systems not only requires technological changes, but also cultural, structural and institutional changes. In addition, despite the relevance of the government to transforming energy system, many other actors and interests are involved, which limits the role to be played by governments. A final complication is that the transformation process does not take place in isolation within national boundaries, but that it requires and involves cross boundary co-operations in addition to collaborations at the national and sectoral level, which are all vital for its successful implementation.

The process of transforming the energy system from its early realization towards an established system passes through different phases. Rotmans et al. (2001) distinguish four different transition phases. 1) A predevelopment or exploration phase, 2) take-off phase, 3) A breakthrough phase, 4) A stabilization phase. In addition to analyzing the phases, transitions can be studied at different aggregation levels, to track development over the course of time and compare them with each other. A well-known conceptualization is the Multi-Level Perspective (MLP) in which three nested levels are distinguished Kemp and Rip 1998, Geels 2002, Geels 2005): the niche (micro) level, the meso level of (socio-technical) regimes and at the macro level the landscape level. Negro (2007: 23) following Rotmans et al (2001), describe three similar aggregation levels as follows:

- Micro-individual or individual actors, e.g., firms, environmental movements
- Meso-networks, communities, and organizations
- Macro-conglomerates of institutions and organizations, e.g. a nation or federation of states)

Another way to study the transformations of energy system is by focusing on the innovations needed and the innovation systems in which they emerge. The focus of this paper is therefore on the relevance and applicability of the National Innovation system concept to transforming energy system, including its implications in transnational and trans-sectoral bases. It will describe the essentials of the National Innovation Systems concept, before comparing sectoral, regional and technology-oriented innovation systems and evaluating the concepts to their relevance to energy sectors.

1. National Innovation Systems: concepts and issues

Innovation is often defined as the capacity of applying new knowledge or recombining existing knowledge in a new way with the purpose of improving productivity or creating new or improved products (goods and services) and processes. It is increasingly acknowledged that innovation consists of technical and non-technical change; the latter can comprise social, organisational, institutional changes, although not necessarily always every one of them. The mutual influence of technical and non-technical aspects has also been referred to as the co-evolutionary development of technology and society. Innovation can take place at different levels, not only at the level of artefacts and at the level of organisations, but also at the level of supply chains, industrial sectors and even society.

Another definition has been provided by Smits (Smits 2002: 865): *"[innovation is] a successful combination of hardware, software and orgware, viewed from a societal and/or economic point of view… Innovation is a complex process that takes place at the level of specific products, businesses and sectors, as well as the level of national and international communities."* In this definition hardware relates to the material equipment, software refers to knowledge including tacit knowledge, while orgware refers to organisational and institutional conditions influencing the development and functioning of an innovation (Smits 2002: 865). This definition thus explicitly refers to the level of socio-technical systems and the necessity of technical and non-technical innovations for realising successful innovation.

Nowadays innovation, whether commercial or non-commercial, is thus considered not to follow a simple linear model. Instead it involves multiple dimensions, as well as multiple actors and happens in a context having systemic characteristics. To cover all these aspects (evolutionary) economists have proposed the concept of innovation systems. Innovation systems have been defined as "all important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion, and use of innovations" (Edquist 1997: 14; Edquist 2001: 2).

Originally, Innovation System was introduced as the concept of national innovation system (NIS) by Christopher Freeman who coined the expression in his book 'Technology Policy and Economic Performance: Lessons from Japan' (Freeman 1987). In this book Freeman identified several major elements in the Japanese system of innovation to which its economic and innovative success could be attributed. Since then, the NIS concept is gaining importance and in fact has become an essential guideline for countries to address policy issues regarding economic success and national competitiveness. According to Lundvall (1992), the NIS can be defined as: *"...the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge…and are either located within or rooted inside the borders of a nation state."* The national innovation system approach stresses that the flows of technology and information among people, enterprises and institutions are key to the innovation process and as such to national competitiveness and economic development. Whereas, country's policy along the NIS lines can assist in pinpointing mismatches within the system, both among institutions and in relation to government policies, which can thwart technology development and innovation.

Writers using the innovation system approach and researching the overall innovative abilities of countries instead of the development of a specific technology point to the important role that institutions at the state level play in innovation (e.g. Kamp 2002, Freeman 2002). Along with educational and training systems, other important parts (or sub-systems) are the capital system, especially the supply of venture capital and long-term finance and the rules under which such funds are allocated, the legal system granting ownership of new inventions and new knowledge (e.g. patent legislation), the political system and governmental policies in areas of science, technology and economics and in labor markets (Nelson 1993; Smith 1997; Ehrenberg and Jacobson 1997). In addition to the relevance of institutions, aspects that are emphasised (after Edquist 1997) include a focus on innovation and learning, the relevance of a historical perspective for explaining current strengths, weaknesses and path dependencies, an emphasis on interaction and interdependence among actors and networks of actors.

Kern (2000) puts three subsystems in the centre of the innovation (see Figure 1): the system of knowledge production, the system of knowledge transfer and dissemination and the system of knowledge application in which companies turn the knowledge into products, services and processes. In the view of Kern, as shown in Figure 1, the financing (sub) system and the regulatory (sub)system must be seen as facilitating the core of knowledge production, knowledge transfer and knowledge application. Kern acknowledges the relevance of education, but has not added this as an additional sub-system. Similarly, sub-systems reflecting (end-) use of the products and services, as well as public acceptance and societal feedback could be seen as other additional sub-systems functions and added to Figure 1. Finally, Kern (2000: 7) argues that each sub-system provides a particular function that is performed by sets of interrelated actors. Thus, each of the sub-systems depicted in Figure 1 also reflects a function.

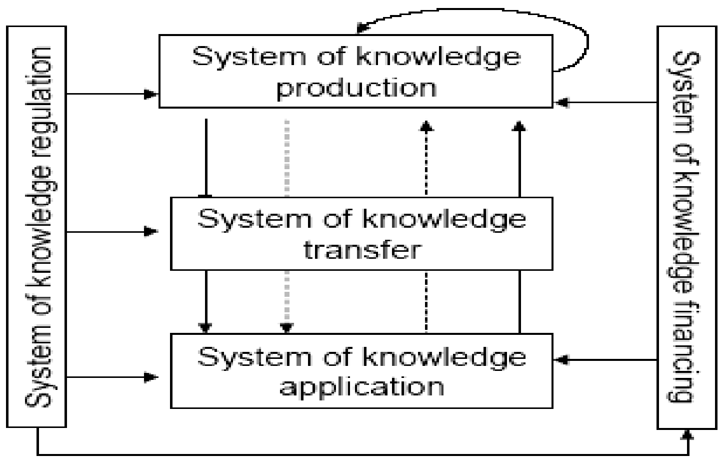

Figure 1. (National) Innovation System (source: Kern 2000: 7)

The NIS concept has gained huge popularity among academics as well as policymakers. It has been and is used as a concept providing explanatory power, as well as a framework for the analysis of factors influencing the innovative capabilities of countries and an approach to policy-making. Despite the growing popularity of the NIS concept, there is no consensus on several key issues. Differences can be found in (1) definitions, (2) where the system boundaries should be put, (3) what is included within the system boundaries, (4) how institutions are defined and (5) what functions should be provided by innovation systems. For a discussion on some of these issues, as well on the emergence and development of the NIS concept, see also Shariff (2006).

With regard to different definitions this is illustrated by Table 1, which contains several definitions that can be found in the literature (Source: Kern 2000, OECD 1997).

Table 1: Definitions of National Innovation Systems (Kern 2000: 3)

Freeman (1987): "…the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies."
Lundvall (1992): "…the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge…and are either located within or rooted inside the borders of a nation state."
Nelson (1993): "…a set of institutions whose interactions determine the innovative performance…of national firms."
Patel and Pavitt (1994): "…the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country."
Metcalfe (1995): "…that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies."

The second issue and the third issue include the distinction between the narrow approach and the broad approach to innovation systems (Lundvall 1992). In the narrow approach the focus is on the actors that are involved in producing and diffusing knowledge. In contrast, the broad approach assumes that innovation system encompass all elements and aspects that affect learning, the development of new knowledge through R&D, as well as to turn this knowledge into products, services and production processes. The broader approach also includes sub-systems, such as the regulatory system, the production system, the financing system, and sometimes even the education system, as well as end-users. Jacobsson and Johnson (2000: 631) take an intermediate view and refer to actors, markets, networks and institutions. The second issue and the third issue also refer to that innovation systems can have a different scale and scope. In addition to national innovation systems, innovation systems can be trans-national, regional, sectoral as well as technology-oriented (e.g. Freeman 2002, Carlsson 2002, Hekkert et al 2007), which are further discussed in Section 3.

Though most authors agree strongly on the importance of institutions in innovation systems, the issue is that institutions are defined in different ways. Two different ways of defining institutions can be distinguished (Kern 2000). First, institutions have been defined as “formal structures with an explicit purpose”, which in general refers to organizations. Second, institutions are defined as a set of rules, laws and norms that guide and pattern behavior of both individuals and actors (e.g. Lundvall 1992). The latter type of definition is more in line with how institutions are conceptualized and defined in social sciences: institutions are there in general defined as rules that guide and pattern behavior of actors and individuals. In institutional theory cognitive, regulative and normative rules are distinguished (e.g. Scott 2001). Formal rules can be regulations, standards, laws, while normative rules can be role relationships, values, behavioral norms and cognitive rules are belief systems, innovation agendas, problem definitions, guiding principles, search heuristics. A set of interrelated rules can make up a regime, such as a technological regime (e.g. Rip and Kemp 1998) or a socio-technical regime (Geels 2002, Geels 2005). Institutions in a sense are path dependent and hence time-oriented. Such regimes and institutions are helpful for (Edquist and Johnson 1997):

- Reducing uncertainty, either by providing information about the behavior of other people or by reducing the amount of information needed.
- Managing conflicts and cooperation between individuals and groups.
- Providing incentives to engage in learning and searching.
- Providing resources.

A final issue that is debated concerns the functions that innovation systems should provide. Different types and sets of functions have been proposed, though differences to a certain extent depend on the type of innovation system (like national, sectoral, technology-oriented). This issue returns in Section 4.

3. Sectoral, regional, technology-oriented and trans-national innovation systems

In addition to the national innovation system, several varieties have been proposed, as, depending on the purpose of the inquiry, the most useful one might not coincide with national borders (Carlsson 2006: 58). For instance, comparing different countries on a set of variables reflecting aspects of their national innovation system (like for instance is done by the OECD), does not allow for identifying or explaining what industries perform well in terms of international competitiveness or the contribution to economic growth. This has resulted in concepts like sectoral innovation systems (e.g. Malerba 2002) and the related cluster concept of Porter (Porter 1990). Secondly, as each country has regions that flourish socio-economically, while others may decline, and certain sectoral innovation systems have strong spatial boundaries, such as Silicon Valley, this has resulted in regional innovation systems. Thirdly, technology-oriented innovation systems have been proposed also referred to as technological systems. Such systems may or may not be geographically and institutionally localized within nations or regions, but they may have links to actors and networks in other countries that are involved in the same technological system (Carlsson 2006: 58). Elsewhere, discussions on differences and similarities of these different types of innovation systems have been provided (e.g. Carlsson et al 2002, Freeman 2002).

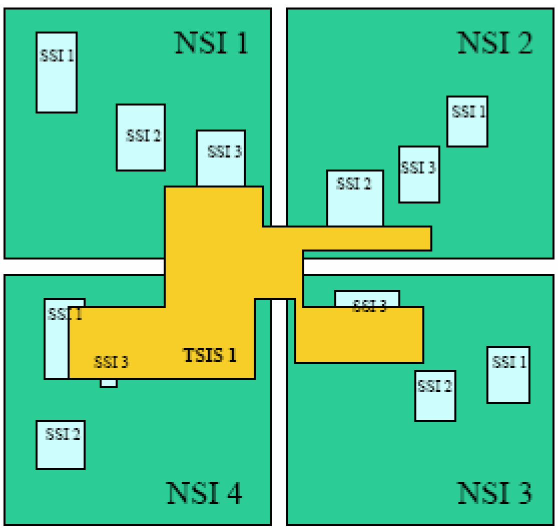

Figure 2 boundary relations between different systems of innovation (NSI is National Innovation System, SSI is Sectoral Innovation System, TSIS is Technology-oriented Innovation System). Source: Hekkert et al 2007)

However, it has also been emphasized by Freeman (2002) that 'successful' sectoral and regional innovation systems are backed and guided by the institutions of a successful national innovation system and the successful coordination and alignment among the different sub-systems, not only at an instrumental level, but also at a holistic or national cultural level. Freeman (2002) uses the industrial revolution that started in the 18th century in the UK to illustrate this. Briefly, due to cultural and institutional changes at the national level that occurred during the century before the industrial revolution enabled the industrial revolution to take off in the UK. Freeman distinguishes the sub-systems science, technology, culture and entrepreneurship, which is a slightly different typology than the sub-systems proposed by Kern (2000, see also Section 2). Freeman argues that despite technological and scientific leadership during the 17th century neither the Chinese empire, nor the Italian city-states managed to reconcile the different sub-systems, whereas this happened in the UK in a way that it enabled the industrial revolution.

It has been argued by various authors (e.g. Hekkert et al 2007) that the focus in innovation system studies is too much on the statics, whereas the dynamics are in general neglected. By contrast, Carlsson et al (2002) have argued that the approach in innovation system studies does not a priori has to focus on static or comparative static analysis. Whereas statics are emphasized in studies of national innovation systems as well as the cluster studies in the sense of Porter (1990), in studies of sectoral innovation systems, technology-oriented innovation systems and regional innovation systems the dynamics are much more included in the analysis.

Despite the importance of institutions at the national level and how these have materialized into institutional arrangements and institutional structures (at the national level), there currently emerges a growing interest into trans-national innovation systems (e.g. Freeman 2002, Carlsson 2006), and how this development relates to economic globalization (e.g. Archibugi et al 1999) including the globalization by multinational corporations (MNCs).

In a recent review on the internationalization of innovation systems by Bo Carlsson (2006), he argues that until the 1990s the internationalization of R&D went considerably less far than in case of other activities of MNCs, especially production. However, since the early 1990s firms increasingly rely on international networks to exploit new knowledge and competences from centers of excellence abroad. At the same time they remain strongly influenced by the national innovation system of their home countries. When internationalization of technology and innovation systems occurs, this takes place through industry clusters that include internationally operating firms and regional innovation systems (in which centers of excellence are rooted), whereas national innovation systems are less important here. In the actual internationalization the international networks related to such industry clusters and centers of excellence are crucial. It must be noted that the focus is here on the internationalization of the R&D part, thus on the generation of new knowledge. It must therefore be noted that this knowledge has also to be turned into competitive products and services that meet the demands of local markets (as also discussed in Section 2 by proposing additional sub-systems like the educational sub-system, the end-use sub-system and the sub-system of public acceptance and public debate). A final note: apart from the firm-driven dynamics it must be realized that in the EU internationalization of innovation systems is strongly stimulated to enhance competitiveness. This includes mobility of scientists, stimulating industrial clusters and cooperation in sectors where scale strongly matters like the aircraft industry and by establishing the supra-national European Research Area that includes forming (partly virtual) clusters of scientific excellence.

4. Functions of innovation systems

In order to make different types of innovation systems 'work', it is widely assumed that they need to fulfill a certain set of functions. For this purpose various sets of functions have been proposed, and a discussion has been provided elsewhere (Hekkert et al 2007, Negro 2007). These functions allow us to measure and predict capability of innovation system and to somehow 'quantify' the system's functional part. As a point of departure we are taking two sets of functions proposed by Kern (2000) and Hekkert et al (2007) for further discussion.

Kern (2000) distinguishes three core functions: (1) production of knowledge; (2) transfer and dissemination of (new) knowledge, and; (3) application and use of knowledge by companies turning knowledge into new products, services and processes. In addition, he distinguishes two additional enabling or facilitating functions, which are (4) financing the production, diffusion and application of new knowledge and (5) regulation and stimulation by the government.

While Hekkert define seven system functions; (1) entrepreneurial activities; (2) knowledge development; (3) knowledge diffusion through networks; (4) guidance of the search; (5) market formation; (6) resource mobilization and (7) advocacy coalition.

If we compare the two proposed set of functions (see table 2), we come to conclude that in spite of referring to certain similar functions i.e., knowledge development, knowledge transfer and diffusion, financing functions, these are two different sets of functions which will lead to differences in system's functional output.. Kern's set of functions explicitly provides us with a function responsible for 'regulations and incentives by government', as the entire process of producing, diffusing and applying knowledge, as well as financing is guided by regulations, standards, laws, and incentives provided by governmental policies. While in Hekkert set of functions, two functions; 'market formation' and 'advocacy coalitions' operating separately do define this function to some extent, but not purposefully and comprehensively. In Hekkert's set of functions 'guidance of the search' is additional and dynamic function, which is not defined as such in Kern's set. Similarly Hekkert define 'entrepreneurial activities' as a separate function and it cannot be compared with 'knowledge application' as defined by Kern. As 'knowledge application' cannot be always a case of entrepreneurship, while otherwise is always true and hence seeks for more dynamic role.

This difference is fundamental as the two sets are proposed to address differently oriented innovation systems. Kern's defined set of functions are more generic and meant to address loosely bounded innovation systems. While, Hekkert's set of functions is pointing more towards technology-oriented innovation system. We are taking the set of functions defined by Hekkert for our further discussion, as it is closer in defining the process of 'transforming the energy system'.

Table 2: Comparison of the two sets of functions

Functions following Kern (2000)	Functions following Hekkert et al (2007)
1. Knowledge production	2. Knowledge development 4. Guidance of the search
2. Knowledge transfer and diffusion	3. knowledge diffusion through networks
3. Knowledge application (by firms)	1. Entrepreneurial activities 5. Market formation
4. Financing functions 1-3	6. Mobilization and allocation of resources
5. Regulation & stimulation by the government	
	7. Advocacy coalitions

Function 1. Entrepreneurial Activities

In the words of Linda Kamp (2007) this function is *sine qua non*, that is no innovation or application of new knowledge is possible without entrepreneurship. Entrepreneur can be an individual, group of people, firm or even sometimes government acts as an entrepreneur. This is the very activity or role which is responsible to introduce innovation in the market. Innovation system concept seeks for and provides support to entrepreneurship.

Function 2. Knowledge development

Knowledge development is another important function of innovation systems. Knowledge develops by learning, while there are four types of learning processes, namely learning by searching, learning by doing, learning by using and learning by interacting. According to Lundvall, it is the central activity within innovation system. Knowledge development acts as a fuel to entrepreneur activities. Knowledge development is cumulative and path-dependent; following this it determines 'spectrum of choices' available to entrepreneur.

Function 3. Knowledge Diffusion through Networks

This function performs vital role of bringing required knowledge to the different system actors, supporting the innovation process. It favors in time information exchange among knowledge developers, people involved in production processes, government and market actors etc. This function through the provision of networks also boosts the processes of learning by using and learning by interacting. The existence of interactive networks in a system helps, efficient utilization of resources and consequently, in organizing the whole process of innovation.

Function 4. Guidance of the Search

This is yet another function necessary for efficient utilization of resources, especially learning and knowledge mechanisms. Since resources are limited, specific path or foci have to be chosen. Guidance of the research can come from earlier goal setting or by feedbacks delivered through networks during on going process of innovation. It can also come from market incentives and can be motivated by government's priorities i.e., research projects in health or basic sciences.

Function 5. Market Formation

This function helps successful introduction of a new product into the market. It argues for manipulation of market phenomenon such as initiating protecting mechanisms for the new product to be successful against incumbent one. Sometimes market for the new one is created by employing social, political or economic pressures for the new technology and its products i.e., sustainable energy technologies.

Function 6. Resource Mobilization (and allocation)

Well guided resource allocation and mobilization is another important function of the innovation systems. Resources are crucial to take-off innovation from the initial stage up to the final stage; it includes financial and human capital. Resources act as a fuel to whole process and are vital to fulfill every other system function.

Function 7. Advocacy Coalitions

This function of innovation system's concept seeks for the coalition among different actors present within system boundaries. It includes entrepreneurs, new knowledge developers and actors which are being profited by old and established product or processes. It makes coalitions and adjustments so as to minimize the, financial and infrastructural loss, impact of sunken investments etc, suffered either by old beneficiaries or by failed innovation carriers.

The above-mentioned functions represent the functional capability of technologically oriented innovation system and favors provision of regulations, institutes and organizations carrying out these functions within specific boundaries of innovation systems. But here, it must be noted that these functions are interdependent and enforce each other in specific system boundaries. The absence of anyone of the 'functions of innovation system' may seriously undermines the overall functional capability of the system i.e., deficiency of Function-6 will effect badly Function-1 and Function-5. It is therefore argued that every function is equally important and these can represent innovation system only in aggregation.

5. Relevance of the (N) IS to transforming the energy system

As discussed earlier in the introduction that the energy system constitutes large socio-technical system and its transformation demands involvement of social, economic, technological and political factors and influence these subsequently. Now, here in this section we will evaluate the applicability of innovation systems concept in transforming the energy system.

To start with technology-oriented innovation systems, this concept has been elaborated and tested for a range of emerging renewable energy technologies (e.g. Negro 2007, Negro et al 2007, Jacobsson and Bergek 2004, Jacobsson and Lauber 2006, Kamp 2007). The focus has in general been on dynamics through the use of functions as well as other characteristics. This type of analyses helps strongly to monitor and explain the emergence of new technologies in the sense of newly emerging niches and where they do not (yet) manage to get entrenched in current energy systems and the dominant regimes guiding these systems.

Sectoral innovation systems are usually associated with entire industries or industrial clusters within countries, such as car manufacturing, the chemical industry, agriculture and the food industry, oil and gas extraction, etc. We have already mentioned in Section 1 that the energy system should be thought of various socio-technical systems like the electricity system, the mobility system, various industrial production systems, as well as cooling and heating of buildings. Many of these systems can be associated with sectoral innovation systems, all being crucial to transforming the entire energy system. Whereas technology-oriented innovation systems may serve as a framework to study the dynamics of new sustainable energy technologies, sectoral innovation systems may serve as a framework to analyze the broader context of the sectoral innovation system that may both constrain and enable the emerging technology and in which various new emerging technologies (and their associated technology-oriented innovation systems) may compete for resources and support by various actors. As developments in different sectoral innovation systems that make up the energy system may benefit from each other, this refers to trans-sectoral linkages.

It has been argued in Section 3 that historically changes at the level of the national innovation system as well as at the overall cultural level and the level of national identities precede the rise and fall of regional and sectoral innovation systems. The implication for transforming the energy system is at least twofold. Firstly, if the various sub-systems and related functions of the National Innovation System perform well this may fuel the sectoral innovation systems needed for transforming the energy system. Secondly and maybe even more importantly, the cultural sub-system as well as the overall culture and (national) identity are crucial, which in the case of making the energy system sustainable, calls for a paradigmatic change with regard to national culture or the cultural subsystem.

With regard to regional innovation systems, these might be important when innovations in certain technologies become highly localized, for instance certain biomass based energy technologies in certain regions of Germany.

Finally, trans-sectoral and trans-national aspects of innovation systems can be illustrated in an indicative way, but cannot be regarded yet as trans-sectoral or trans-national. Firstly, if technology-oriented innovation systems cross sectoral borders, than this is a trans-sectoral linkage. This has also been shown for technologies like ICT and for technological transitions like the steam engine in shipping (Geels 2002). With regard to internationalization of innovation systems this is driven by international networks involving firms, as well as regional innovation systems and centers of excellence that attract foreign firms. Despite of the growing relevance of these developments and links, these have not yet been regarded as trans-national innovation systems.

Is there more relevance of the functions of innovation systems to transform the energy systems? For this purpose, we aim to relate the 'functions of Innovation System' with 'Multi-phase concept' of the Transition theory. According to 'Multi-phase concept', system transition such as a process of transforming the energy system can be divided into four phases (Rotmans et al 2001): namely, predevelopment or exploration phase, take-off phase, breakthrough phase and stabilization phase. The purpose of this division of transformation process along timeline is to make the analysis more manageable. It provides us vital information concerning demands and requirements of 'system transition' at particular instant of the process. Following is the brief introduction to the four phases:

1) Predevelopment phase: It represents the stage when new relevant knowledge is produced and cumulates. New insights into the present technologies are made and new technologies are envisioned. It is the stage that generates value of variety and is mostly marked by knowledge creation, learning by doing and by creative destruction.
2) Take-off phase: This stage is marked by selection and evolution of technological trajectories appearing against established technological regimes. That is why this is the stage in which innovations needed to be tried and grow in protected market spaces against well established old ones.
3) Breakthrough phase: This is the phase in which structural changes in the system begins to emerge and embed. In this stage co-evolution of externalities, i.e. technical, social, economic, eventuate and construct the new system.
4) Stabilization phase: In this phase the new system becomes fully developed indicated by reduced speed of the change and increased returns of adoption for a new system. The new systems have now become so established in current routines, infrastructure, and legal frameworks that they have become as established system in and of themselves (Negro).

It should be noted that this division of transformation process is only to study and analyze system change along timeline. However in practice many innovations or transitions do not go beyond first or second stage during specific course of time. This failure is not always due to some technical breakdown but absence of innovation supporting system can also turn, otherwise a technical triumph into a failure. Now, here in the following paragraphs we will discuss that how the functions of innovation systems support transformation process along the individual phases discussed above.

As *predevelopment or exploration phase* is characterized by generation of new knowledge. Now, if we go back to the functions of innovation systems as described in the previous section; function-2 (knowledge development) and function-4 (guidance of the search) fulfills the purpose of new knowledge production. While function-6 (resource mobilization) is also applicable during this stage as it provides and directs resources to be used to initiate and go along the process of knowledge development.

In the *take-off phase* the most relevant is function-3 (knowledge diffusion through networks), while function-1 (entrepreneurial activities), -5 (market formation) and -7 (advocacy coalition) are also necessary system functions at this stage. Function-3 does the job of knowledge provision to firms and to other actors from knowledge developers and carries back the feedback to the developers through interactive networks. Function-1 is necessary for test and trial purposes of the new technology against incumbent one and hence for take-off phase. This stage is also marked by the competition between different technology trajectories and this is boosted by more and more entrepreneurial activities. This function also needs functions 5 and 7 for its success. Function-5 forms often needed protected market spaces for innovations to be able to take-off i.e., niche markets. Function-7 provides coalitions among different stakeholders necessary to alleviate change process.

System change through *breakthrough phase* is supported by function-7 (advocacy coalitions) as changes in regulations, laws, taxes, and norms etc, are most needed at this stage. We argue here that one of the function namely 'regulations and incentives by government' defined by Kern (2001) is more relevant in this phase as it explicitly favors provision of innovation supporting 'regulations and laws'. Amendments in 'regulations and laws' in favor of new technology are often necessary to remove institutional lock-in in the present system. This removal of institutional lock-in provides space for new technology to slip in and favor development of new institutional framework for its support.

Than comes the *stabilization phase*, which is marked by the end of transition process. It is characterized by stability; in this stage transformation has been completed and potential for design improvements are at its maximum level. The phase gathers profit makers, investments and other business activities around it and is now part of a society. Again it's the innovation system concept which helps developing co-evolution of these externalities. Now the question arises how and why a system i.e. innovation system, makes compromises between exploration stage at one end and stabilization phase at the other?

6. Conclusions

In this paper we have explored the concept of innovation systems before evaluating it on its relevance and applicability to the transformation of energy system. We have found that in the literature on innovation systems various common characteristics can be found, of which emphasis on institutions can be seen as the most important one. Differences have been identified too and relate to definitions, system boundaries and what is exactly included within these boundaries, how institutions are defined and what functions should be provided by innovation systems. Furthermore, various types of innovation systems have emerged and it has been argued that each of them is relevant to studying the transformation of energy system.

Whereas innovation systems are defined as systems of knowledge production and turning this knowledge into products, services and processes, energy system should be seen as sectoral systems of production and consumption that are sub-systems of the energy system. As transforming energy system requires creation and utilization of new knowledge, this clearly explains the relevance of innovation systems and innovation systems concepts to making energy system transform. However, current innovation systems associated with energy system are strongly focused on and embedded in current issues and practices (guided by related institutions) and therefore the innovation systems need to be transformed too in order to become well equipped to support the transformation of energy system.

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