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A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers

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www.chalmers.se/tme/EN/centers/ride

RIDE/IMIT Working Paper No. 84426-008

IMIT – Institute for Management of Innovation and Technology
RIDE – R&D and Innovation' and 'Dynamics of Economies

VINNOVA

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Institute for Management of Innovation and Technology

84426-008

Forthcoming in Foxon, T., Köhler, J. and Oughton, C. (eds): *Innovations for a Low Carbon Economy: Economic, Institutional and Management Approaches* (preliminary title), Edward Elgar, Cheltenham.

Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers[1]

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1. Introduction

For a range of reasons, the energy system needs to be transformed to a sustainable one, both in terms of supply and demand. On the supply side,[2] this transformation will probably involve both "sailing ship" technologies (Rosenberg, 1976) (e.g. carbon sequestration) and technologies that use renewable energy sources. For the latter, no single technology can replace fossil fuel within a relevant time period. A transformation, therefore, needs to involve the development and diffusion of a whole range of low carbon innovations. Currently, we are witnessing a rapid diffusion of, e.g., wind turbines, solar cells and different technologies to provide heat and power from biomass (district heating boilers, CHP, small-scale pellet burners etc.). In the pipeline, we see wave power and gasified biomass (fuel for vehicles or CHP plants). To have an impact, each of these technologies have to go through a lengthy (several decades long), uncertain (in terms of markets, technology and policy) and painful (many obstacles and failures) process of development and diffusion.

[1] We are grateful to STEM, VINNOVA and KSI for funding our work.

[2] In this paper, we deal only with the supply side and exclude more energy efficient technologies, changes in infrastructure and human behaviour that jointly may reduce the demand for energy.

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From a firm perspective, the associated challenges have been discussed in the literature on technological discontinuities (e.g. Utterback, 1994; Christensen, 1997). From a meso perspective, the process of diffusion of a specific new technology is reflected in the formation and evolution of technological innovation systems (TIS). Between these two levels, there is a clear interaction: On the one hand, new TIS are built “bottom-up” by entrepreneurial initiatives that develop new technology and bring it to the market. On the other hand, entrepreneurial actors have little chance of succeeding in driving a discontinuity without the formation of a supporting system (Van de Ven, 1993).

Whereas the role of policy is to enable a number of different TIS to simultaneously move towards a phase where growth is self-reinforcing (Jacobsson and Bergek, 2004), there are also strong reasons for entrepreneurial actors to pay more attention to “sector building” in an early phase (Suchman, 1995; Van de Ven, 1993). This implies that both policy makers and entrepreneurs need to identify appropriate system-building activities. Put briefly, such activities should be directed towards increasing the strength of inducement mechanisms and reducing the power of various blocking mechanisms (cf. Johnson and Jacobsson, 2001). However, the identification of such system strengths and weaknesses is a difficult task that so far has received very little attention in management, entrepreneurship and innovation policy research. We propose that a ”functional” approach to innovation systems, i.e. a “meso level” approach that is firmly rooted at the micro level, could go some way towards remedying this weakness (cf. Johnson, 2001; Johnson and Jacobsson, 2001; Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004; Negro et al., 2005; Hekkert et al., 2006; Bergek et al., 2006a).

The usefulness of the approach is to identify means of speeding up the diffusion of a technology that has been defined as desirable by entrepreneurs, policy makers and/or other relevant stakeholders.[3] It takes its starting point in a framework for understanding innovation system dynamics that not only captures the structural elements of a system but also what is actually achieved in terms of a set of key processes – henceforth labelled “functions in innovation systems” – which determine innovation system performance. Through an empirical mapping and analysis of these functions, system weaknesses (i.e. weak functions), can be identified. Policy makers and entrepreneurial firms can, thereafter, choose which of factors

[3] Thus, we do not evaluate the desirability of a particular technology, but assumes that such a decision has already been taken.

blocking these functions to give particular attention to. The first purpose of this paper is to outline this framework and discuss some methodological issues related to applying it.

From a low carbon innovation perspective, where radical change is required and new innovation systems need to develop in competition and conflict with old ones, functions related to the institutional framework have received far less attention in research than those related to actors, markets and networks (which have been discussed at some length in the management and entrepreneurship literature, as well as in the literature on innovation systems). The second purpose of this paper is, therefore, to elaborate further on two institution-related functions: “Legitimation” and “Influence on the direction of search”, and to discuss how they may be influenced by entrepreneurial action and policy makers.

The paper is structured as follows. Section 2 outlines the structural elements of a TIS and discuss dynamics in terms of these. Section 3 moves from “structure” to “functions”, identifies seven functions and gives an illustrative example of solar cells in Germany. Section 4 deals with some methodological issues related to capturing dynamics in terms of functions. In Section 5, we discuss two of the functions more in detail and use case studies to illustrate how they may be influenced by various actors. Section 6, finally, summarizes our findings and makes some concluding remarks.

2. Structure and dynamics of Technological Innovation Systems

An innovation system is a system in the most general sense, in terms of a configuration of parts connected and joined together by a web of relationships. A technological innovation system (TIS) may be defined as (Carlsson and Stankiewicz 1991, p. 111): “.... network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology.“ Thus, it has three components: actors, networks and institutions. These are not necessarily technology-specific, but may be shared by several technological innovation systems.

The *actors* include firms within the whole value system (cf. Porter, 1985). For instance, in the case of solar cells they include manufacturing of machinery to make thin film solar cells, machinery suppliers to wafer producers, cell and wafer producers, engineering firms designing and delivering whole systems, roof and façade manufacturers, electricians, architects etc. They also include other organisations, such as universities, industry organizations, bridging organizations, other interest organizations (e.g. Greenpeace) and government bodies.

In the course of the formation of the TIS, each new firm that enters the system brings knowledge, capital and other resources into it. Entrants experiment with new combinations, fill “gaps” (e.g. become a specialist supplier) or meet novel demands (e.g. develop new applications). A division of labour is formed and further knowledge formation is stimulated by specialisation and accumulated experience (e.g. Smith, 1776; Rosenberg, 1976). Similarly, other organisations enter the system and enrich it, for instance in the form of universities providing specialised courses, bridging organisations that act as meeting places and interest organisations that promote the technology in the public arena.

The *networks* can be of various types. “Learning networks” can link suppliers with users, related firms (Porter 1998), competitors or university researchers and constitute important modes for the transfer of tacit and explicit knowledge. They also influence expectations of the future, i.e. perceptions of what is possible and desirable, that guide specific investment decisions (Carlson and Jacobsson, 1993; Geels and Raven, 2006). “Political networks” or advocacy coalitions, made up of a range of actors sharing a set of beliefs, seek to influence the political agenda in line with those beliefs in competition with other coalitions (Smith, 2000; Rao, 2004). In the political science literature, non-technology specific coalitions are in focus, which is reasonable considering that the political debate over, say, climate change, is not necessarily focused on specific TIS. However, for a new technology to gain ground, technology specific coalitions need to be formed and to engage themselves in wider political debate. As firms and other organisations enter into the TIS, these two different types of networks have to be formed, enlarging the resource base of the individual firm (in terms of information, knowledge, technology etc.) and giving the collective a voice in the political arena.

The third element is *institutions*, i.e. legal and regulatory aspects, norms and cognitive rules that regulate interactions between actors, define the value base of various segments in society, influence firms’ decisions and structure learning processes (problem agendas, guiding principles, ways to do business, etc) (cf. Scott, 1995). Institutional change (and by implication its politics) is at the heart of the process whereby new technologies gain ground (Freeman and

Louca, 2002). This implies that firms in competing TIS do not only compete in the market for goods and services but also to gain influence over institutions. As Van de Ven and Garud (1989) put it, "…firms compete not only in the marketplace, but also in this political institutional context. Rival firms often cooperate to collectively manipulate the institutional environment to legitimize and gain access to resources necessary for collective survival …" (p. 210).

The formation of a new TIS, thus, involves three structural processes: entry of firms and other organisations, formation of networks and institutional alignment. These processes begin in a formative phase (Jacobsson and Bergek, 2004), which has three distinguishing features. First, there is a high uncertainty facing entrepreneurial actors, investors and policy makers in terms of technologies, markets and regulations (Kemp et al., 1998). Second, it may last for decades (Carlsson and Jacobsson, 1997). Third, the process in which the constitutive elements are put in place is a cumulative process of many small changes (cf. Van de Ven and Garud, 1989).

Once the elements are put in place, the TIS is in a position to shift to a growth phase (Carlsson and Jacobsson, 1997; Porter, 1998) and begin to have an impact on the energy system. Any change in a component in the system, e.g., a new entrant or a change in the institutional set-up, may trigger a set of actions and reactions that propel the system forward. The boundaries, in terms of both actors and knowledge, may consequently alter, sometimes quite rapidly (Carlsson et al., 2002). As it does so, a chain reaction of powerful positive feedbacks may materialize, involving many (or all) of the constituent components of the innovation system. For instance, new entrants may be induced by market opportunities and generate positive externalities that reduce entry costs for further entrants; networks may become more dense; institutions may continue to be reshaped to suit the evolving needs of the new system and universities may expand their research and education in the relevant knowledge fields (cf. Porter, 1998). The linkages between these may, thus, turn out to be circular, setting in motion a process of cumulative causation (Myrdal, 1957). Indeed, these virtuous circles are central to a development process – as they are formed, the evolution of the TIS becomes increasingly self-sustained.

Tracing the evolution and interdependencies of the structural elements in a given TIS as they are "put in place" is, of course, doable. Yet, although we know that these structural elements need to be built up, we cannot assess the “goodness” of a particular structure other than by relating it to an outcome in terms of diffusion (e.g. cumulative wind power installations). However, in order to inform various actors of what needs to be done to speed up the rate of diffusion, we need to be able to explain the current (slow) rate of diffusion and identify weaknesses in the TIS. We suggest that this should be done, not in an ad hoc fashion but by introducing a second level of key processes in TIS development, bridging the gap between structure and performance. These key processes are here referred to as “functions of innovation systems”. The functions address what is actually happening (or being achieved) in the TIS and have a direct influence on the ultimate performance of the system. The main advantage of focusing on functions is, thus, that we can separate structure from content.[4]

3. Functions and innovation system dynamics

The concept of “functions in a technological innovation system” refers to the (positive or negative) contributions of one or several system component(s) to the overall “goal” of developing, diffusing and using innovations within a particular technological field (Bergek, 2002). The analogy here is not the functional school within sociology, but more general systems theory. We begin by outlining seven functions and then proceed to discuss internal and external sources of dynamics in structure and functions. An illustrative case study concludes the section.

3.1 Proposed set of functions[5]

Based on several literature reviews (in economics, management, organisational science, political science, economic geography) and a number of empirical studies, we propose the following set of functions to be applied when mapping the key processes in innovation system dynamics.[6]

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[4] In a TIS, there is not a one-to-one connection between components and functions; each function may be filled or influenced by different components and each component may influence several functions.

[5] This section draws heavily on Bergek et al. (2006a), Negro et al. (2005) and Suurs and Hekkert (2005).

[6] A systematic mapping of the innovation systems around biomass digestion, biomass gasification, and biofuels in the Netherlands (Negro et al., 2005) shows that the suggested functions correspond well to empirical data (Hekkert et al., 2006).

Function 1: Knowledge development and diffusion

This is the function that is normally placed at the heart of a TIS in that it is concerned with the breadth and depth of the knowledge base of the TIS and how well that knowledge is diffused and combined in the system (Bergek et al., 2006a). It is, thus, closely related to the concept of "learning", which is at the core of the IS approach: "the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning" (Lundvall, 1992). The sources of knowledge development include not only academic and firm level R&D, but also activities such as learning by doing, learning by using, imitation etc. A precondition for learning to occur on a system level is knowledge diffusion, which often takes place through various learning networks, as described above.

Function 2: Influence on the direction of search

If a TIS is to develop, a whole range of firms and other organisations must perceive entrepreneurial opportunities in the new system and enter into it. There must then be sufficient incentives and/or pressures for the organisations to be induced to do so. The second function is the combined strength of such factors. It also covers the mechanisms having an influence on the direction of search *within* the TIS, in terms of different competing technologies, applications, markets, business models etc.

These mechanisms are not solely related to markets or governments; they are also shaped by the interpretation of opportunities by entrepreneurial actors (Shane et al., 2003). This is often an interactive and cumulative process of exchanging ideas between technology producers, technology users, and many other actors, in which not only the technology itself but also opportunities are dynamic. Consequently, the factors inducing firm entry or influencing technology choice within a TIS are not "controlled" by one organisation, but by a variety of system components as well as factors that go beyond technology specific components (se section 3.2 for an elaboration on this point). Their strength is the combined effect of, for example:

- Visions and belief in growth potential
    - Incentives from changing factor and product prices
    - Growth occurring in TISs in other countries
    - Changes in the "landscape" (Geels, 2002), e.g. the climate change debate
    - Expectations (van Lente, 1993)

- Actors’ perceptions of the relevance of different types and sources of knowledge
- Regulations and policy
- Articulation of demand from leading customers (von Hippel, 1988)
- Technical bottlenecks or “reverse salients” (Rosenberg, 1976; Hughes, 1983)

Function 3: Entrepreneurial experimentation

As emphasized in section 2, a TIS evolves under considerable uncertainty in terms of technologies, applications and markets. Uncertainty is a fundamental feature of technological and industrial development and is not limited to early phases in the evolution of a TIS but is a characteristic of later phases as well (Rosenberg, 1996). It goes far beyond the realm of the R&D lab; it involves the heterogeneous context where R&D meets government policies, competitors and markets. In this context, the latest technological insights need to be complemented by, e.g., consistent decisions on standards and long-term policy targets and R&D agendas may need to be adjusted to adapt to changing norms and values in society.

From a social perspective, the way to handle uncertainty is to ensure that many entrepreneurial experiments take place. This function is closely related to the first function, but is focused on how the potential of new knowledge, networks and markets are turned into concrete actions to generate, realise and take advantage of new business opportunities. Through risky experiments, knowledge can be collected on the functioning of technology under different circumstances, and reactions of consumers, government, competitors and suppliers can be evaluated (Kemp et al., 1998; Raven, 2005). In the course of their experimentation, many technologies and firms will fail, some will succeed and a social learning process will unfold.

Function 4: Market formation

For an emerging TIS, markets may not exist, or be greatly underdeveloped; potential customers may not have articulated their demand (or even have the competence to do so) and price/performance of the new technology may be poor. Rosenberg (1976) puts it like this:

> “Most inventions are relatively crude and inefficient at the date when they are first recognized as constituting a new innovation. They are, of necessity, badly adapted to many of the ultimate uses to which they will eventually be put; therefore, they may offer only very small advantages, or perhaps none at all, over previously existing techniques. Diffusion under these circumstances will necessarily be slow …”.

Protected spaces in the form of “nursing markets” (Erickson and Maitland, 1989) are normally required so that a “learning space” is opened up, in which the TIS can find a place to be formed (Kemp et al., 1998). Within such an environment, actors can learn about and develop the new technology and expectations can be formed. One option is the formation of niche markets (Schot and Hoogma, 1994) for specific applications. This involves the identification by entrepreneurial actors (or policy makers) of market segments in which the advantages of the new technology are valued higher than its disadvantages (e.g. in terms of cost). Another option is to create (temporary) competitiveness through regulations, such as the 250 MW demonstration programme for wind power in Germany in the early 1990s (Bergek and Jacobson, 2003).

Nursing markets may later give way to "bridging markets" (Andersson and Jacobsson, 2000) that allow for volumes to increase and for the TIS to grow. Here, policy may enhance entrepreneurial opportunities and learning by enlarging a protected space. Examples of this may be the feed-in-laws in Germany and Spain or the tradable green certificate scheme in Sweden. Finally, in successful TIS mass markets may evolve, often several decades after the formation of the "nursing" market.

Function 5: Resource mobilization

Resources are necessary as a basic input to all the activities within the innovation system. Hence, we need to understand the extent to which the TIS is able to mobilize *human capital* (through education in specific scientific and technological fields, but also in entrepreneurship, management and finance), *financial capital* (seed and venture capital, diversifying firms, government funds made available for long term R&D and/or demonstration etc.), and *complementary assets* (complementary products, services, network infrastructure, etc.).

Function 6: Legitimation

As is widely acknowledged in organization theory, legitimacy is a prerequisite for the formation of new industries (Rao, 2004) and, we would add, new TIS; the new technology and its proponents need to be considered appropriate and desirable in relation to relevant institutions as judged by relevant actors in order for resources to be mobilised, for demand to form and for actors in the new TIS to acquire political strength. Legitimacy also influences expectations among managers and, by implication, their strategy.

Legitimacy is not given, however, but is formed through conscious actions by various organizations and individuals in a process of legitimation, which eventually may help the new TIS to overcome its “liability of newness” (Zimmerman and Zeitz, 2002). This process may take considerable time and is often complicated by the fact that new TISs seldom emerge in a vacuum, but instead need to relate to and compete with established TIS. Regardless of whether the new TIS may become part of an incumbent regime or threatens to overthrow it, parties with vested interests may oppose this force of “creative destruction” and defend existing TISs and the institutional frameworks associated with them.

Partly as a consequence of this, it is difficult for individual actors to influence the legitimacy of a TIS and successful entrepreneurial influence is more likely to be take the form of concerted actions by advocacy coalitions (Aldrich and Fiol, 1994; Suchman, 1995). If successful, these may grow in size and influence and may become powerful enough to brisk up the spirit of creative destruction. The scale and successes of these coalitions are directly dependent on the available resources and the future expectations associated with the new technology.

Function 7: Development of positive externalities or ”free utilities”

The concept of “positive externalities” is used in neo-classical economics to describe out comes of investments that the investor cannot fully appropriate the benefits of. This implies that other actors may enjoy “free utilities” such as “spill-overs” in terms of knowledge development (e.g. R&D), reduction of uncertainty and strengthened legitimacy. These may all increase with the number of entrants into a new TIS. Other “free utilities”, such as the emergence of pooled labour markets and specialised intermediate goods providers, may be stimulated by firm co-location (Marshall, 1920). As Porter (1998) underlines, positive externalities are central to the formation of clusters (and innovation systems). However, it is a process that is not independent of the other functions but rather indicates the dynamics of the system on a functional level.

3.2 Driving forces and blocking mechanisms: internal versus external forces of change in structure and functions

Each TIS has some unique features in terms of its structure, i.e. in the character and constellation of actors, networks and institutions. This structure evolves, in part, as a result of the internal dynamics of the TIS. However, there are also external factors that interact with internal processes and influence the evolution of many TIS simultaneously, for instance the recent institutional change in the form of tradable emission permits. Geels (2002) conceptualises the internal or technology-specific elements as a "niche" and refers to the more general elements as "regimes" (a sector-level concept[7]) and "landscapes". The interplay between the niche and the regime is a central part of the evolutionary process.

This distinction is useful and echoes the work of Myrdal (1957, p. 18) who showed a keen understanding of the interplay between internal and external sources of dynamics and even suggested that "… the main scientific task is … to analyse the causal inter-relations within the system itself as it moves under the influence of outside pushes and pulls and the momentum of its own internal processes".

In our framework of "functions in innovation systems", the distinction between internal and external influential factors is perhaps less visible but nonetheless there. Indeed, the whole notion of functions was developed to handle an *integration* of technology-specific and more general factors. Thus, as two of us put it some years ago (Johnson and Jacobsson, 2001, p. 93):

> "In the context of an emerging technological system, we can define its borders by analysing what promotes or hinders the development of these functions. These factors may be fully technology specific, but may also influence several technological systems simultaneously. Hence, they can be derived from a system perspective using different units of analysis: technology, industry, nation."

The driving forces and obstacles to system development may, thus, be either technology-specific (internal to the structure of the emerging TIS) or more general (external). A technology-specific driving force may be demand from a leading customer. Examples of more general forces are the climate change debate or the Chernobyl accident, which "destabilise" (Raven, 2005) the dominant regime and open up windows of opportunities for new niches.

For an emerging TIS, it is particularly vital to identify blocking mechanisms, i.e. factors that provide obstacles to the development of powerful functions and, therefore tilt the selection environment in favour of incumbent technologies, and the dominant regime (cf. Johnson and Jacobsson, 2001; Unruh, 2002). A technology-specific blocking mechanism may, for instance,

[7] The regime concept is situated at the level of organizational fields (Geels, 2006), which "primarily deals with the nature of relations among nodes within a social space, in the same vein as concepts, such as 'industry systems' … and 'societal sectors'…" (Mazza and Strandgaard Pedersen, 2004, p. 877).

be poorly developed networks that limit knowledge diffusion and legitimation. An external blocking mechanism may come in the form of highly organized incumbents that defend their markets and investments and make sure that institutions are continued to be aligned to the dominant technologies. “Sailing ship” effects (Rosenberg, 1976), i.e. improvements in the performance of conventional technologies, may be another blocking response from the regime. External blocking mechanisms may also be traced to the emergence of other TIS that compete both in the market and in the political arena. A current case is that of fossil gas in Sweden where a “battle of institutions” is taking place with the proponents of biomass CHP (Jacobsson, 2006). Implicit in our framework is, therefore, not only considerations of dominant TIS in the regime but also of the impact of emerging, and competing, TIS.

3.3 An illustrative example: The German TIS for solar cells

The German case of solar cells (see Jacobsson et al., 2004; Jacobsson and Lauber, 2006) is a useful illustrative example. We will describe the emergence of that TIS in functional terms and show how the functions were driven by internal changes in the technology-specific structural elements as well as by external factors and how the functions interlocked and began to drive the TIS forward in a (partly) self-reinforcing way.

Beginning in the end of the 1970s, institutional changes occurred which began to open up a space for solar power. *Knowledge development* was fostered by Federal RD&D programmes (institutional change) that provided opportunities for universities, institutes and firms to enter and to search in many directions. In the period 1977-89, as many as 18 universities, 39 firms and 12 research institutes received federal funding. The major part of the research funding was directed towards cell and module development and the focus was on one particular design (crystalline silicon cells), but funds were also given to research on competing designs (i.e. thin-film technologies). In addition, funds were allocated to the exploration of issues connected to the application of solar cells, such as the development of inverters.

The first demonstration project (institutional change) took place in 1983. In 1986, it was followed by a demonstration program, which by the mid-1990s had contributed to building more than 70 larger installations for different applications. This only had a minor effect in terms of *market formation*, but *influenced the direction of search* among smaller firms and led to a degree of *entrepreneurial experimentation*. Thus, it was effective as a means of enhancing *knowledge development* in terms of application knowledge. *Resource mobilisation* took place not only in the form of federal funding but also in terms of investments by these smaller firms as well as by four larger firms which had entered into solar cell production. These larger firms were particularly important as they accepted large losses over a sustained period of time.

An external factor, the nuclear accident in Chernobyl in 1986, had a deep impact in Germany in terms of the value base (institutional change). The Social Democrats committed themselves to phasing out nuclear power; the Greens demanded an immediate shutdown of all plants. The same year, a report by the German Physical Society, warning of an impending climate catastrophe, received much attention, and in March 1987 chancellor Kohl declared that the climate issue represented the most important environmental problem. As a consequence, there was a consensus among political parties to foster renewable energy which simplified a subsequent process of *legitimation* of solar power. In 1990, the 1,000-roof programme (institutional change) for *market formation* and applied *knowledge development* was initiated, focusing on small solar cell installations.

Whereas the 1,000-roof programme was successful, the market was not large enough to justify investments in new production facilities for the solar cell industry, in particular as the industry was running with large losses. The industry now expected a follow-up to the 1,000 roof programme, but no substantial programme emerged. If the industry was to survive, market formation had to come from other quarters than the federal level. This led to intensified efforts to mobilise other resources, a process which demonstrated the politics of *legitimation*.

The most important help came from municipal utilities. In 1989, the federal framework regulation on electricity tariffs was modified to permit utilities to conclude cost-covering contracts with suppliers of electricity using renewable energy technologies. On this basis, local activists, representatives from a number of interest organisations and the solar cell industry formed a TIS specific advocacy coalition (network formation) and petitioned local governments to enforce such contracts on the utilities. Eventually, most Länder allowed such contracts (institutional change), and several dozen cities opted for this model. Due to this and other initiatives, *market formation* continued after the 1,000-roofs programme.

At this point, the development of the TIS began to characterised by cumulative causation, i.e. market formation began to impact on other functions, which through a subsequent feed-back loop strengthened *market formation* even further. In particular, we want to point to two sequences.

First, a number of new (often small) firms entered into and enlarged the TIS, strengthening *resource mobilisation*. Among these were both module manufacturers and integrators of solar cells into facades and roofs, the latter moving the market for solar cells into new applications. Individual firms were “first movers” into new applications and provided *positive external economies* to follower firms in that they made visible new business opportunities; they reduced uncertainties and *influenced the direction of search* of other firms. As a consequence, the range of *entrepreneurial experiments* was broadened; *knowledge development (applied)* was strengthened, as was *market formation*.

Second, the large number of cities with local feed-in laws revealed a wide public interest in increasing the rate of diffusion, which various environmental organisations could point to when they drove the process of *legitimation* further. Lobbying by the German solar cell industry was also at this point intensified: Industry representatives argued that to continue production in Germany without any prospects of a large home market would be questionable from a firm’s point of view. A promise of a forthcoming support programme was then given and two large firms decided to invest in new, large plants in Germany; *resource mobilisation* was dramatically strengthened.

In this particular case, the main need for system building activities did not lie in promoting knowledge development or entrepreneurial experimentation but in enhancing market formation and legitimation. The key issues for both policy makers and entrepreneurs were, therefore, related to these two functions. In a “bottom-up” process, activists, firms, interest organisations and politicians at Ländern and federal levels drove a process of legitimation with the aim of changing the institutional framework to open up a larger market space. Eventually, this process was successful, and with the forthcoming programs the TIS shifted into a growth phase (as from 1998). At this point, the diffusion process became increasingly self-sustained and characterized by a degree of autonomous dynamics.

4. Methodological aspects of capturing dynamics

Through the separation of structure from key processes at the functional level, the functions approach provides a systematic method of mapping determinants of TIS dynamics and to identify the need for system building activities. It, thus, enhances the analytical power of the IS approach.

This is particularly important from the perspective of an entrepreneurial firm, which cannot influence all functions simultaneously but instead needs to decide what functions to influence and what organisations to link up to in order to influence other functions (Van de Ven, 1993). Policy makers normally have a quite restricted policy domain and, thus, have to make similar choices as the entrepreneurs with respect to which functions to influence directly and which to influence via other actors. In order to come to these decisions, entrepreneurial firms and policy makers, thus, need to understand how and how well the key processes of “their” TIS currently work (in comparison to what could be expected and/or wanted) and what the main problems are.

There are three complementary ways of capturing system dynamics using a functional approach. First, with a longitudinal analysis, we can draw several consecutive maps of the *functional pattern* of a TIS and, thus, capture how it changes over time. We may also capture the dynamics resulting from the interaction of functions by mapping feedback loops between functions (Bergek and Jacobsson, 2003).

Second, system performance may be evaluated in terms of the *functionality* of a particular innovation system, i.e. in terms of how well the functions are served within the system. Process goal can then be formulated in functional terms, e.g. widening the scope of entrepreneurial experiments.

Third, the functional pattern and its evolution can empirically be linked to and explained by the specific set of driving forces and blocking mechanisms for each TIS (Bergek and Jacobsson, 2003). This implies that the key issues for firm strategy or government policy are readily definable as and when such an analysis has been completed.

As a consequence, the functions approach has the potential to deliver a) clear set of targets for entrepreneurial and policy driven system building activities (process goals) and b) specifications of the particular inducement and blocking mechanisms driving the functional pattern of a specific TIS. In what follows, we will briefly outline some methodological aspects of these three types of analyses.

4.1 Mapping the functional pattern of the TIS

The first step in a functional analysis is to describe what is actually going on in the TIS in terms of the key processes, where we come up with a picture of an "achieved" functional pattern, i.e. a description of how each function is filled in a system. This step has no normative features, i.e. involves no assessment of the "goodness" of the current functional pattern.[8]

Mapping the functions includes analysing both the present state of the function and its determinants. For example, in order to understand the formation of markets, we need to analyse both actual market development and what drives the formation of markets. Analysing the determinants is usually more difficult and requires in-depth knowledge of the TIS.

A number of different indicators and data types may be used (see Table 1), depending on the purpose of the study. Data sources include interviews and/or questionnaires as well as secondary data supplied through, e.g. trade journals and catalogues, official statistics, annual reports, newspapers etc. Industry associations are often a particularly valuable source of information, but they may be unavailable in an early phase of industry development. Detailed insights in the fulfilment of functions are, however, gained primarily by means of interviews.

TABLE 1: *Examples of indicators and data types used to map TIS functions*

FUNCTION	EXAMPLES OF INDICATORS/DATA TYPES
Knowledge development and diffusion	R&D projects Patents Bibliometrics Investments in R&D Learning curves Number of workshops and conferences Size and intensity of learning networks
Influence on the direction of search	Factor/product prices (e.g. taxes and prices in the energy sector) Regulatory pressures (e.g. quota systems for renewable electricity) Government/industry targets regarding the use of a specific technology Estimates of future growth potentials Articulation of interest by leading customers.
Entrepreneurial	Number of new entrants

[8] Thus, the concept should not be interpreted as implying that the pattern is either repeated or optimal (Bergek et al., 2006a).

experimentation	Number of diversification activities of incumbent actors Number of experiments with the new technology. Degree of variety in experiments (e.g. number of different applications)
Market formation	Number, size and type of markets formed Timing of market formation Drivers of market formation (e.g. support scheme)
Resource mobilisation	Volume of capital and venture capital Volume and quality of human resources (educational data) Volume and quality of complementary assets
Legitimation	Attitudes towards the technology among different stakeholders Rise and growth of interest groups Extent of lobbying activities Political debate in parliament and media
Development of positive externalities/free utilities	Strength of political power of TIS actors Activities aiming at uncertainty resolution Existence/development of clear division of labour, specialised intermediates and/or a pooled labour market Information and knowledge flows

In some recent work, one of us has developed a more quantitative method, the so-called process approach for the purpose of mapping functional patterns (see, e.g., Negro et al., (2005)). This approach conceptualises development processes as sequences of events (cf. Abbot, 1995; Poole et al., 2000) that take place within the TIS under investigation, in terms of what the central subjects do or what happens to them. The data collection is focused on following system-level events that are reported in, e.g. newspaper archives and professional journals. These events can be workshops on the technology, the start up of R&D projects, expressions of expectations about the technology in the press, announcements of resources that are made available, etc. All mapped events are then allocated to the seven functions and categorized as either a positive or a negative influence. When all events are allocated to functions they can be plotted in figures, one for each function. This gives a quick and strong visible presentation of the functional pattern over time (see Figure 2, which shows the number of events allocated to the function “Influence on the direction of search” for biofuels technologies in the Netherlands).

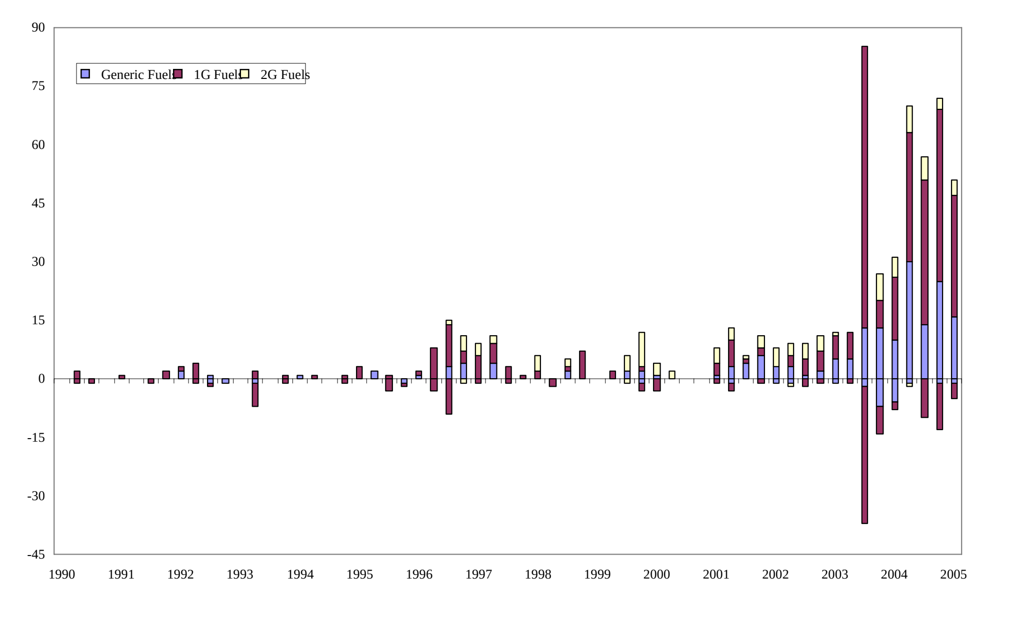

Figure 1: Illustration of events influencing the direction of search for biofuels in the Netherlands.

Source: Suurs and Hekkert, (2006)[9]

4.2 Assessing TIS functionality

The functional pattern only tells us *how* the TIS is functioning. In order to assess system functionality – i.e. *how well* the system is functioning (Bergek and Jacobsson, 2003) – we need ways to evaluate the relative "goodness" of a particular functional pattern. This is one of the major challenges for analysts. Bergek et al. (2006a) identified two bases for an assessment:

- The functional pattern can be analysed with respect to the current life cycle phase of the TIS, i.e. the strength and weaknesses of functions may be related to the particular needs of each phase.
- A TIS may be compared with systems in other regions or nations in terms of performance (in order to get the right gauge in an assessment in terms of what development is reasonable to expect of the TIS) and functional pattern (in order to identify critical functions and/or different ways to achieve the same level of functionality).

[9] The increasing number of events over time indicates increasing attention for the emerging technologies. The figure also distinguishes between first and second generation biofuel technologies, showing how different emerging technologies compete in influencing the direction of search.

With a given functionality of a TIS it is possible to specify goals in terms of how the functional pattern should develop in order to reach higher functionality, i.e. towards a targeted functional pattern. Such goals (e.g. broaden the knowledge base or widen the range of experiments) can be seen as "process goals". That is, goals are expressed in terms of the seven key processes in contrast to final goals (such as growth). Process goals have an advantage in that they are "closer" to the various types of system building activities pursued by entrepreneurial actors and/or policy makers. In addition, final goals may be close to impossible to define in an early phase, since the uncertainty regarding what the TIS may be able to achieve, and what is desirable to achieve, in the long term is very high.

4.3 Linking functional pattern to inducement and blocking mechanisms

In an attempt to explain the functional performance of a TIS, it may be useful to specify the linkages between the functions and the relevant inducement and blocking mechanisms (see section 3.2) in the form a figure, such as Figure 2. Restricting ourselves to blocking mechanisms, the figure identifies the most important ones for renewable energy technology in Sweden in the end of the 1990s and how these obstructed the formation of powerful functions. Six blocking mechanisms were identified. One of these was "weak network failure" by which we meant that tight networks had not developed (i.e. connectivity was weak). Without tight learning networks (see section 3.1), positive external economies in the form of knowledge development /diffusion (first function) did not materialise which led to poorly functioning technical systems for burning pellets and to R&D in solar collectors that emphasised performance rather than price/performance.

In constructing a figure of this kind, there are a few lessons that may be considered. First, care should be taken to include only the most important linkages. The analyst therefore needs to abstract from non-essential relationships and justify the choice of those deemed to be essential. Second, a given mechanism may influence several functions (e.g. lack of long-term government vision in Figure 2). Third, this influence may be both direct and indirect. The indirect effect may be of extreme importance, such as for instance when legitimation influences the direction of search (as is normally the case). Of course, if a particular blocking mechanism influences a number of functions (directly and indirectly) this mechanism constitutes a key problem for entrepreneurial actors and policy makers to focus their attention on. What often comes out of an analysis is a list of three to five such key issues.

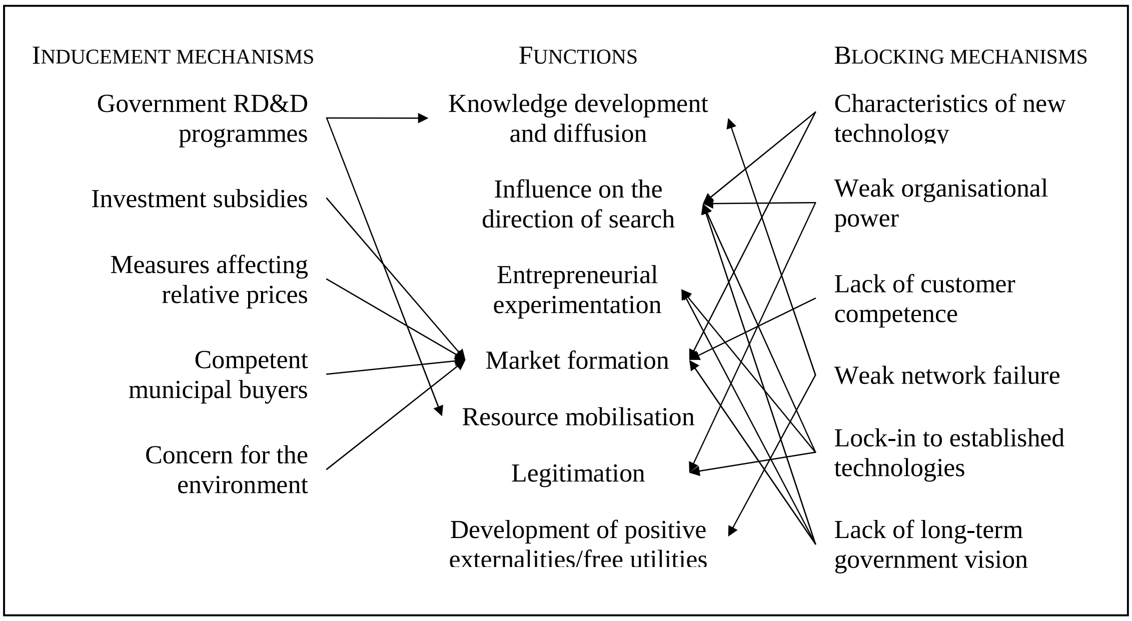

Figure 2: Example of illustration of linkages between inducement/blocking mechanisms and functions in the case of renewable energy technology in Sweden (adapted from Johnson and Jacobsson (2001))

5. Management of legitimacy and expectations

Having outlined the entire approach of functional analysis and discussed a set of methodological issues related to applying it, we will now proceed to discuss in more depth two functions, that have been neglected in much literature on innovation systems but which are of particular relevance for low carbon innovation. The two functions are “legitimation” and “guide the direction of search” (where we focus in particular on the “management of expectations”) and both are closely related to the institutional framework. [10]

Their relevance for low carbon innovation stem from some features of the energy system which a) obstructs market formation and b) suggests that the political risks for entrepreneurs are particularly high. There are two features obstructing market formation. First, as was underlined in section 3.1, new technologies often have a cost disadvantage in comparison to incumbent technologies. Unlike a new consumer good, where a buyer may be willing to pay extra for a high performance in some dimension, however, renewable energy technology does not offer any direct benefits for the individual buyer or investor (but reduce society’s costs in terms of e.g. CO_2 reduction).

[10] The following paragraph draws on Jacobson and Bergek (2004).

Second, incumbent technologies are often subsidised. For instance, according to UNDP (2000) conventional energy received subsidies in the order of 250-300 billion USD yearly in the mid-1990s. Incumbent technologies are also subsidised indirectly as there are various types of negative external economies associated with them. Although difficult to estimate, the European Commission suggests that "the cost of producing electricity from coal or oil would double…if the external costs such as damage to the environment and to health were taken into account" (Milborrow, 2002, p. 32). These features suggest that it is particularly difficult to form markets for renewable energy technology.

The continuation of various subsidies to incumbents reflects their influence on the institutional framework. Indeed, the debate over the future of the energy system involves intense lobbying over both policy goals and design of the institutional framework where the proponents of the established energy system use their influence to oppose institutional change that would disadvantage their technologies. Policy making is, thus, a highly political business where advocates of low carbon technologies often meet opposition from powerful and highly organised incumbents. This opposition is strengthened by the discontinuous nature of much of the technical change involving low carbon innovations. Not only is the knowledge base of the new technologies different, but they also imply a shift from centralised to decentralised power production. This, of course, suggests that both large utilities and the power equipment oligopoly are additionally hesitant towards adopting low carbon technologies and that the political risks for entrepreneurs pursuing these may be perceived to be very high.

At the heart of this "battle over institutions" lie distinctly different views on the legitimacy of different technologies. Poorly developed legitimacy for (some) low carbon technologies, coupled with market formation problems, implies that uncertainties are particularly high, expectations are poorly developed and that the function "influence the direction of search" remains weak. Hence, for low carbon innovation, management of these two functions are particularly critical and in what follows, we will go more deeply into both entrepreneurial strategies and possible policy contributions with respect to these functions.

5.1 Management of legitimacy

In an early phase of TIS development there is often great uncertainty with regards to the meaning and context of the new technology or product. This was, for example, the case in the early US automobile industry:

> “As a novel technology, the automobile *per se* was unfamiliar to prospective consumers and putative inventors. Consumers were confused because the source of power, the number of cylinders, systems of steering and control, and the mode of stopping were topics of considerable controversy … The only point of agreement about the automobile was that it could not be powered by animals.” (Rao, 1994, p. 33)

A first step for entrepreneurial actors is to define the new technology or product and make it seem reliable and understandable in the eyes of users and producers (Aldrich and Fiol, 1994). This often involves the development of a dominant design or common standard (cf. Galvin et al., 2005), but may also be the result of education of potential users or intermediary actors. For example, a Swedish manufacturer of solar collectors developed an information file which was distributed to local Heating, Ventilation and Sanitation firms in order to enable them to answer questions regarding solar heating and to market solar collectors to individual house-owners (Johnson and Jacobsson, 2001).

However, legitimation needs to go beyond this: The new TIS needs to achieve broader institutional alignment in cognitive, normative and regulative dimensions, either through conformance to established institutions (cf. Ashforth and Gibbs, 1990; Suchman, 1995) or by institutional change. For example, suppliers of ethanol fuel for cars may either decide to advocate for an increased use of low-ethanol blends for gasoline cars or for specialised fuels requiring new cars. The former would imply conformance both in the sense of following the European Commission’s fuel specifications for gasoline and in the sense of allowing customers to remain true to their refuelling habits as well as their car preferences, whereas the latter would require each potential user to change cars, and possibly also filling stations, and would imply non-conformance to gasoline specifications.

In many cases of low-carbon innovation, conformance will be difficult to achieve since institutions are locked-in to established technologies and tend to block the development of new technological options (Unruh, 2000). For example, in the Swedish environmental permit review process, wind power plants of 10 MW or larger have, until recently, been judged according to similar criteria as large (200 MW or more) combustion plants, paper and pulp plants and iron works. Moreover, since discontinuous technological change often implies substantial uncertainty with regards to future relevant systems-in-use and value networks (Rosenbloom and Christensen, 1994), it may be difficult for entrepreneurial actors to choose which institutional framework to conform to. For example, in the case of black liquor gasification in Sweden, an attempt by entrepreneurial actors to win legitimacy, in the eyes of incumbent utilities and government policy makers, by adapting the technology to the current electricity output maximization norm in that field failed because potential users in the paper and pulp industry adhered to established "industry recipes" – in particular with respect to what business they were supposed to be in (pulp and paper vs. electricity production) – and, therefore, favoured technology features improving the quality of the pulp and the flexibility of the pulping process (Bergek, 2002).

Participants in the new industry may, therefore, need to influence the institutional framework in order to achieve alignment between institutions and the new TIS (Jacobsson and Bergek, 2004). Such "institutional entrepreneurship" may either imply manipulation of established institutions or the establishment of new institutions (Ashforth and Gibbs, 1990; Suchman, 1995; Zimmerman and Zeitz, 2002).

This strategy is usually perceived to be an option only in later stages of the life cycle of a TIS, when the proponents of the new technology has gained some strength and political power (cf. Aldrich and Fiol, 1994) In an early phase, it may be too big a challenge for individual entrepreneurial actors to master, especially considering the risk that initiatives to change institutions may trigger a response from stronger and more legitimate incumbent actors opposing change. Therefore, institutional entrepreneurship may require coalitions of actors to "run in packs" (Van de Ven, 1993; 2005). Indeed, as argued by Suchman (1995) "the limited literature on 'institutional entrepreneurship' suggests that one key may lie in the capacity of affected organizations to reach beyond their boundaries and act in concert" (p. 591).

An empirical example of institutional entrepreneurship is the one of the German Electricity Feed-in Law (EFL), which remained in place, and was further developed, in spite of strong opposition from incumbent actors, due to the political struggle of a coalition made up by advocates of wind and hydro power initially, and solar power later (see Box 1). It illustrates well that the proposition that "If participants in an industry are successful at creating legitimacy for their industry, then all the participants in the industry will benefit; if unsuccessful, they all will suffer" (Deeds et al., 2004, p. 11).

BOX 1: *The story of the German Electricity Feed-in Law*

The concept of the EFL was first put forward by associations supporting hydro, wind and solar energy. It was passed by the Bundestag in 1990 in an all-party consensus. The law required utilities to connect generators of electricity from renewable energy technology to the grid and to buy the electricity at a rate amounting to 90% of the average tariff for final customers. However, when the Feed-in Law began to have an impact on the diffusion of wind turbines, the big utilities started to attack it both politically and in the court system. Their efforts to change the law seemed promising at first. In 1996, a complaint lodged by the utilities association VDEW with the European Commission's DG Competition gained some support and the German Ministry of Economic Affairs then proposed to reduce rates on the occasion of an upcoming amendment.

By then, however, the number of wind turbine owners had increased greatly in Germany and some local turbine manufacturers had emerged. Together, these formed an industry association which grew in strength as the market expanded. By teaming up with other associations in the renewable energy field they mobilised a large number of people to take part in the discussions over the future of the law. A very considerable effort was made by the German Wind Energy Association to seek out selected members of parliament and lay out arguments in favour of the law. In this process they were very much helped by the fact that wind energy had become the source of livelihood of a large number of people, in particular in the northwest of the country. Economic arguments could therefore be used, in addition to environmental ones. In 1997, the government proposal to reduce feed-in rates mentioned above led to a massive demonstration bringing together metalworkers, farmer groups and church groups along with environmental, solar and wind associations; the Association of Investment Goods Industry VDMA gave a supportive press conference.

The Bundestag finally voted in favour of keeping the EFL. In a committee vote, the government proposal lost out by a narrow vote of 8–7, and the government even failed to persuade its own MPs. The big utilities' political challenge had, thus, been defeated by a collective of actors. Whereas the law benefited mainly wind power in the 1990s, it was to be reformed in 2000 to include technology-specific payments. After the Red /Green coalition came into power in 1998, the deputies, particularly the Greens, were inspired by the local feed-in laws for solar power (see section 3.3.) and wanted to move this approach to the Federal level. For that purpose they organised a process involving a very large, partly technology-specific advocacy coalition – various environmental groups, two solar industry associations, VDMA, the metalworkers' trade union IG Metal, three solar cell producers and politicians from some *Länder*, e.g. North Rhine-Westphalia. From these organisations and individuals, the Greens received help in terms of both information and support in influencing members of parliament. The Social Democrats for their part had a strong industrial policy interest in re-writing the Feed-in Law. They feared that the 1998 liberalisation of the energy market would lead to a long-term decline in employment in the energy sector and in the associated capital goods industry, which has always been a point of strength of German industry. At this time, the German wind turbine industry had grown to be the second largest in the world and exhibited great dynamism. With liberalisation, the price of electricity dropped, and with it, the remuneration for wind turbine owners. It was then feared that the incentive for further diffusion would be lost and that a less dynamic home market would hurt the German wind turbine industry. Strong renewables legislation, these deputies argued, would put German industrial structure and employment on a more sustainable basis both environmentally and economically.

Sources: Bergek and Jacobsson (2003); Jacobsson et al., (2004) and Jacobsson and Lauber (2006).

Discontinuous technical change obviously may make the process of legitimation particularly difficult. There is, therefore, a need for policy initiatives that may support institutional entrepreneurship. Central to such efforts would be early policies to support the formation of a market space in terms of nursing markets, which in combination with other system building activities may provide entrepreneurs with a learning space and the opportunity to start the legitimation process (see Section 3.1). The market space does not necessarily have to be large and policy initiatives may come from various levels. For example, in German solar cell case, such initiatives came from city, Länder and federal levels (see section 3.3).

As and when a new TIS has passed through the formative phase and comes to a point when it becomes necessary to challenge the prevailing institutional framework head-on, coalitions engaged in institutional entrepreneurship need to be supported by elements of the state in the “battle over institutions”(the outcome of which is very uncertain). Basically, institutions have to be moulded in a way that opens up a larger markets space and enables a process of cumulative causation to be strengthened. The German cases of wind power and solar power demonstrate that such efforts can be successful (see Box 1), but in other cases, incumbents have prevailed.

5.2 Management of expectations (influence the direction of search)

Expectations regarding new technology can be characterized in three types (van Lente, 1995). A first is of *technological- scientific* nature where expectations may influence search in R&D settings. A second is of *strategic* nature where management expects the new technology to raise the performance of the firm. Finally, there are *global* expectations regarding societal trends, for example the often heard expectation that the oil reserves will soon be exhausted. Whereas expectations are quite heterogeneous in terms of subject, source and focus, they have in common that actors use expectations as a resource to legitimise behaviour and to mobilise support (van Lente, 1995).

The “voicing and shaping of expectations” (e.g. Kemp et al., 1998; Raven, 2005) may involve referral to well-known and accepted expectations, such as “hydrogen is seen by many as the fuel of the future” or “the 20th century was the century of ICT, but the 21st century will be the century of biotechnology”. In particular, shaping expectations may be critical in order to acquire enough legitimacy to get access to public R&D funds (van Lente and Rip, 1998), protected learning spaces or industrial partners. Creating a clear vision of a possible future reduces uncertainty and provides various actors with reasons to give support or to participate in activities. These actors include policy makers as well as firms. The former are central to reach in order to influence the design of the regulatory framework (e.g. funding demonstration projects or facilitating grid access for distributed power generation). They are particularly important in policy driven TIS that are likely to depend on further institutional change to shift from a formative to a growth phase. The latter are central to reach not only to acquire partners but also to obtain a critical mass (Van de Ven, 1993). Expectations, thus, influence not only "influence on the direction of search", but also "legitimation" and "resource mobilisation".

When entrepreneurs and governments explicitly realize that expectations may influence the process of technological change, they may act intentionally to shape the dynamics of expectation regarding new technology. Based on counts of appearance of expectations in public media, Alkemade et al., (2006) studied how different actors in the Netherlands influenced expectations regarding biofuels (see Figure 1 and Box 2). Testing of different strategies like a tit-for-tat strategy (entrepreneur responds with positive expectations statement directly after negative expectations statement) and uniform strategy (entrepreneur simply tries to keep its technology positively in the newspaper) showed a significant influence of the management strategy. In emerging technological fields with a strong opposition from the embedded system entrepreneurs may, therefore, form expectation-building networks together with (future) competitors.

The key activity for governments to undertake is to shape incentives and/or pressures for organisations to perceive entrepreneurial opportunities in the new TIS. An obvious measure is to articulate clear visions regarding the new technology, and associated long term goals. A strong back up of such visions by institutional changes (e.g. funding specialized R&D programs, public procurement measures, tax changes etc) may convince entrepreneurs that this new technological direction should be taken seriously and will provide market opportunities. Again, institutional changes aimed at forming early markets are particularly important.

A good example of the effect of long-term policy goals on technology development is the case of zero emission vehicles in California. The Californian Air Resources Board (CARB) launched a Low Emission Vehicle program in 1990, setting progressive goals for the introduction of these vehicles from 1998 onward, which led to changing expectations and a strong increase in R&D activities for low emission vehicle technology as well as to a growing technological variety in R&D efforts (Frenken et al., 2004).[11]

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[11] Similarly, Johnson and Pettersson (1997) showed an increase in patenting activity related to electric vehicles and battery technology following CARB's intervention.

BOX 2: *The role of expectations in the Dutch biofuel innovation system*

The role of expectations is an important factor in explaining the dynamics of the Dutch biofuel innovation system, which has functioned poorly in terms of diffusion: no significant diffusion of biofuels took place in 1990 – 2005, while other European countries were more successful.

In the early 1990s, pressure from the European Union and stories about positive experiences in Germany and France stimulated a number of Dutch entrepreneurs to experiment with first generation biofuels (e.g., diesel from rape seed). Some form of support was needed to make further development attractive for entrepreneurs, but the Dutch government only implemented individual cases of tax exemption. This was due to a strong public debate about biofuels, where both the environmental movement and several well-known energy scientists questioned the use of biofuels as an alternative fuel saying that the environmental benefits were too low to justify subsidies. Due to the contested nature of biofuels, the first entrepreneurs never managed to shape expectations enough for biofuels to become a priority.

Five years later, large players with vested interests in the fossil energy system managed to shape positive expectations for second-generation biofuels (e.g. cellulose-based ethanol and Fisher-Tropsch diesel) with help from energy scientists and the environmental lobby. This resulted in a publicly funded R&D program. The second-generation biofuels was expected to outperform the first generation in all aspects. The given priority to these types of biofuels and the clearly expressed high expectations resulted in the entry of several new actors in the biofuels innovation system.

In 2002, the pressure of the EU to comply with the European biofuels directive put the Dutch government in a difficult position. The second-generation biofuels were not ready for market yet and the only way to comply with the EU directive was by giving priority to first-generation biofuels. Allowing the first generation biofuels to enter the subsidy programs that were up till then strictly accessible for 2nd generation fuels created a large shift in innovation system dynamics. Expectations were shaped and many entrepreneurs entered the innovation system, resulting in an explosion of projects dealing with the construction of biofuel mills, and experiments with using biofuels.

Sources: Alkemade et al., (2006) and Suurs and Hekkert (2005)

6. Conclusions

The purpose of this chapter was two-fold: a) outline an analytical framework – functions of innovation systems – that can be used by both entrepreneurs and policy makers to identify appropriate system-building activities and b) to go into some depth with respect to two functions and discuss how they may be influenced by entrepreneurial action and policy makers.

We began by discussing the constituent structural components of a technological innovation system and identified three key processes at the structural level: entry of organisations, formation of networks and alignment of institutions. We then proceeded to introduce seven key processes at the functional level, that have a more a direct influence on the ultimate performance of a system, arguing that these are shaped by both the technology-specific structural elements and by factors external to that structure. Finally, we argued that process goals can be set in functional terms and the key issues for system building activities (by individual or groups of organisations as well as by policymakers) can be derived from an analysis of blocking and inducement mechanisms.

Conducting analyses of this kind requires a great deal of attention to methodological issues and we discussed three of those: (1) how to ascertain the functional pattern of TIS, (2) how to assess its functionality (goodness) and (3) how to explain and illustrate the functional pattern by a set of inducement and blocking mechanisms.

We further argued that the two functions “legitimation” and “influence the direction of search” are particularly problematic with respect to low carbon innovations. Managing these requires collective efforts by entrepreneurs as well as policy intervention – there are limitations to an entrepreneurial influence on the functional pattern. Entrepreneurs and policy makers may therefore need to coordinate their system building activities.

The framework has nothing to say about the desirability of a particular technology but is restricted to find points where intervention has most effect. The framework bridges innovation systems thinking with that of management (entrepreneurship). In this, it provides the former with a strong micro level foundation and the latter with the necessary meso level linkages. By identifying the key process in system dynamics, in both structural and functional terms, and explaining the strength of these, it presumably has a great deal to contribute to the formulation of strategies and policies to form and expand technological innovation systems centred on a range of low carbon innovations.[12]

[12] It has already proven its usefulness with respect to policy but it is untried as yet from an entrepreneurial perspective, although the work of van de Ven (1993) on very similar lines suggests that it is so.

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