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‘Legitimation’ and ‘Development of positive externalities’: Two key processes in the formation phase of technological innovation systems

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Abstract (100-150 ord)

Responding to the climate change challenge requires a massive development and diffusion of carbon neutral technologies and, thus, emergence and growth of new socio-technical systems. This paper contributes to an improved understanding of the formative phase of new technological innovation systems (TIS) by outlining a framework for analysing TIS dynamics in terms of structural growth and key innovation-related processes (“functions”) and by discussing two of these functions at some depth: “legitimation” and “development of positive

externalities”. Empirical examples are provided from case studies on renewable energy technologies in Sweden. We highlight the problematic role of technology assessment studies in shaping legitimacy and the importance of early market formation for the emergence of “packs of entrepreneurs” that may contribute to legitimation, and discuss how exploitation of overlaps between different TISs may create positive externalities, opening up for a powerful “bottom-up” process of system growth. Associated policy and management challenges are identified.

Keywords: Innovation system, structure, functions, dynamics, formation phase, legitimation, positive externalities, wind power, biopower, solar photovoltaic power, alternative transport fuels

1. Introduction

The literature on climate change makes it plain that much of the capital stock in the energy and transport sector needs to be replaced within three to four decades.¹ This requires a massive development and diffusion of carbon neutral technologies. To be able to facilitate such a transformation, policy makers and others need to understand the key processes in the development, diffusion and utilisation of new technologies. This appreciation is today partly lacking. This is particularly so for those informed by neoclassical economics, which is concerned with the selection of technologies ‘from the shelf’ rather than ‘filling the shelf’ with new technologies.² The latter process is synonymous with the emergence and growth of new socio-technical systems – a messy and difficult process that is yet not fully understood. The purpose of this paper is, therefore, to contribute to an improved understanding of the early and formative phase of new technological innovation systems (TIS) – and to identify associated policy and management challenges.

We begin, in section 2, to develop an understanding of the dynamics of TIS, both in terms of structural growth and key innovation-related processes. We label these latter processes ‘functions’ of the innovation system and all of these are potentially linked to challenges for decision makers desiring to influence the formation of new TIS. In Section 3, we discuss at some length two of the, all in all eight, functions. These are ‘legitimation’ (acquiring a social acceptance of new technologies) and ‘development of positive externalities’ (that underpin complementarities of supposedly competing technologies). The focus on legitimation and external economies is chosen because of an apparent discrepancy between our empirical

findings and the lack of attention given to these functions in the literature on technology management and policy. Empirical evidence is taken from case studies of TISs in Sweden and Germany, centred on three renewable electricity production technologies (biopower, wind power and PV) and a number of alternative transportation fuels (e.g. methanol, ethanol, biogas, hydrogen) in Sweden. These case studies have been thoroughly described elsewhere and will not be detailed here.³ Our main conclusions are given in section 4.

2. The dynamics of technological innovation systems: an outline of a framework

A general definition of a system is a group of components (devices, objects or agents) serving a common purpose, i.e. working towards a common objective or overall function.⁴ In studies of technical change, the concept of ‘technological system’ has been used in two different, but partly overlapping, ways. The first is a socio-technical system specialised on the provision of a particular output that serves some (societal) function, e.g. electricity production or transport.⁵ The second focuses on the development, diffusion and utilisation of new technologies,⁶ and may, thus, alternatively be labelled ‘technological innovation system’ (TIS). Arguably, these two concepts describe different aspects of the same phenomenon: Whereas the first captures all aspects of a “technology delivery system”⁷, the latter focuses on the innovative activities within it. In this paper, we use this more narrow system concept since we are primarily interested in the development and diffusion of new technical solutions.

The components of a technological innovation system are the actors, networks and institutions contributing to the development, diffusion and application of a particular technology.⁸ In line with a number of previous authors,⁹ we also include the technology as such among the components. Each TIS has a degree of uniqueness in terms of its structural components (i.e. some components are exclusively dedicated to the TIS), but components may also be part of several systems simultaneously.¹⁰ In emerging TIS, few specialised components can be expected to exist and the structural overlap with – and dependence on – other systems is, therefore, likely to be particularly large.

Technology includes both artefacts and knowledge.¹¹ Artefacts may come in the form of hardware (e.g. products, design tools and machinery) or software (e.g. procedures/processes and digital protocols). Knowledge is partly found as competence within actors, but also

codified in recipes (text, drawings, etc) or embedded in artefacts. It may be of a more formal (research-based) character or of a more experienced based character.¹²

Actors include firms (and other organisations) along the whole supply chain. For instance, in the case of solar cells they include manufacturing of machinery to make solar cells, cell and wafer producers, engineering firms designing and delivering whole systems, roof and façade manufacturers, electricians, architects and users. They also include universities, industry associations, bridging organisations, interest organisations such as Greenpeace, and government bodies. Although the mere existence of actors in a TIS may in some cases be of great importance for, e.g., legitimacy,¹³ the core of this component is agency.

The *institutional* base of the TIS regulates interactions between actors. Institutions may come in the form of hard regulations (controlled by juridical systems) and in the form of norms and cognitive rules (controlled by social systems). The normative and cognitive dimensions of a TIS are not always easily separated – actors are guided in what they think is right and what they want to do by what they know and are able to do. This interpretation is closely related to the concepts of “limited (or bounded) rationality”¹⁴, “bounded vision”¹⁵ and “path dependency”¹⁶. Taken jointly, normative and cognitive institutions influence decisions and actions in the form of frames¹⁷ or paradigms¹⁸ that structure learning processes (problem agendas, ways to do business, etc). An integral part of these frames are expectations, i.e. beliefs about the future.¹⁹

The formation of *networks* follows not automatically from the entry of various organisations into the TIS, but requires links that turn fragmented components into a system. Of particular importance here are different types of networks between actors. Learning networks link suppliers to users, related firms or competitors, or university to industry. They constitute important modes for the transfer, or sharing, of knowledge and also influence the perception of what is possible and desirable, which guides specific investment decisions.²⁰ Political networks are of equal importance. Policy making takes place in a context where advocacy coalitions, made up of a range of actors sharing a set of norms or beliefs, compete in influencing policy in line with those beliefs.²¹ In addition to these actor networks, artefacts may be linked together in different ways. They may be hard-linked, to make up larger artefacts/product systems (e.g. components in a car), or more loosely linked, in infrastructural networks (e.g. cars and petrol stations).

When a radically new technology emerges, few of these structural components are in place. The TIS must, thus, go through a formative phase, in which the constituent elements evolve and agglomerate through entry of firms and other organisations, formation of networks, institutional alignment and the accumulation of knowledge and physical artefacts.²² This is a cumulative process of many small changes,²³ which can last for decades.²⁴ It is also a process characterised by high uncertainty in terms of technologies, markets and regulations,²⁵ which both investors and policy makers must handle.

Once the elements are “put in place”, the TIS is in a position to shift to a growth phase.²⁶ As and when it does so, a chain reaction of powerful positive feedbacks may materialize, setting in motion a process of cumulative causation.²⁷ Indeed, virtuous circles are central to a development process – as they are formed, the evolution of the TIS becomes increasingly self-sustained.²⁸ Through further positive feedback processes, the TIS may eventually become mature, characterised by a stable structure (or even structural “lock-in”).²⁹ Such a system develops primarily through the forces of its own momentum and is quite resilient to external pushes and pulls.

To analyse this kind of dynamics we suggest that it is fruitful to distinguish a number sub-processes that are directly related to the innovation process, i.e. the development, diffusion and use of new products, processes etc., and that influence the build up of system structures. In Table 1, we outline eight sub-processes and label these “functions”.³⁰ While the exact number of functions is somewhat arbitrary, we suggest that the set covers the key processes in the dynamics of any TIS. These functions have been derived from a rich and multidisciplinary theoretical base, including literature on innovation systems and evolutionary economics but also political science, sociology and population ecology.³¹ Earlier versions of this framework have been applied in a number of empirical studies.³²

TABLE 1: *Functions of technological innovation systems*

Development of formal knowledge	The breadth and depth of the formal, research-based knowledge base and how that knowledge is developed, diffused and combined in the system.
Entrepreneurial experimentation	Knowledge development of a more tacit, explorative, applied and varied nature – conducting technical experiments, delving into uncertain applications and markets and discovering/creating opportunities etc.
Materialisation	The development of (and investment in) artefacts such as products, production plants and physical infrastructure.
Influence on the direction of search	The extent to which supply-side actors are induced to enter the TIS, or

	put more subtly, direct their search and investments towards the TIS. ³⁵
Market formation	Articulation of demand and more “hard” market development in terms of demonstration projects, “nursing markets” (or niche markets), bridging markets and, eventually, mass markets (large-scale diffusion).
Resource mobilisation	The extent to which the TIS is able to mobilize human capital, financial capital and complementary assets from other sources than suppliers and users and the character of this mobilization.
Legitimation	The socio-political process of legitimacy formation through actions by various organisations and individuals. Central features are the formation of expectations and visions as well as regulative alignment, including issues such as market regulations, tax policies or the direction of science and technology policy.
Development of positive externalities (“free utilities”)	It reflects the strength of the collective dimension of the innovation and diffusion process. It also indicates the dynamics of the system since externalities magnify the strength of the other functions.

*Source: Based largely on Bergek et al.*³⁴

In our previous research, we have used these functions to analyse the performance of different TIS.³⁵ We have also shown how policy makers may assess the ‘goodness’ of a specific functional pattern and use it to guide their policies.³⁶ In this paper, however, we focus primarily on the issue of TIS dynamics.

The strength of the functions is determined not only by the influence from structural components (endogenous dynamics) but also by exogenous factors at many levels, e.g. regime/landscape³⁷ or national/sectoral innovation systems.³⁸ This co-existence of internal and external influences was highlighted already by Myrdal, who even stated 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”.³⁹

In an early phase of system formation, exogenous factors may dominate,⁴⁰ simply because the system components are underdeveloped. As the system grows, however, the endogenous dynamics may gain strength, involving extensive linkages between functions. Alterations in the functions impact on the structure of the system and an altered structure of the TIS will, in turn, influence the character of the functions (see Figure 1).

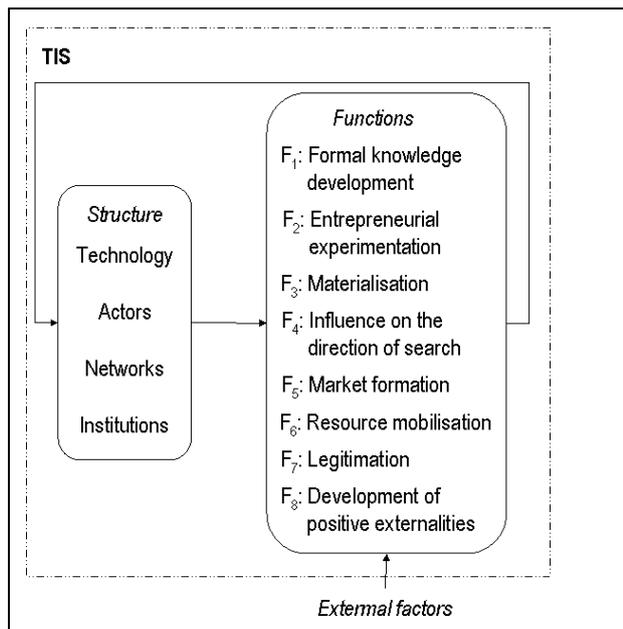


Figure 1: Relations between external influence, structural elements and functions

As an illustrative example of coupled functional and structural development, we will describe the emerging solar cell TIS in Sweden.⁴¹ ‘Legitimation’ was shaped by i) lobbying from political networks in an embryonic solar cell industry ([1] in Figure 2), ii) the climate change debate [2] and iii) experience from “sister” TIS (e.g. that in Germany) [2]. The resulting changes in the institutional framework in terms of norms and regulation [3] in turn strengthened the functions ‘influence on the direction of search’ and ‘market formation’ [4], inducing a number of new firms and users to enter [5]. This strengthened the functions ‘entrepreneurial experimentation’ and ‘materialisation’ [6], also made possible by the availability of imported components [7], and led to structural change in terms of technology [8]. The existence of working and visible PV systems is likely to strengthen ‘legitimation’ [9]. Some of the firms recognised the need, and argued for, collective action and formed an industry organisation for that purpose. In the future, this may improve the process of legitimation further [10] (complete feed back loop), inducing a favourable regulatory framework [11]. This institutional alignment may then stimulate further ‘legitimation’ [12] and ‘influence on the direction of search’ [13] of yet more entrants [14].

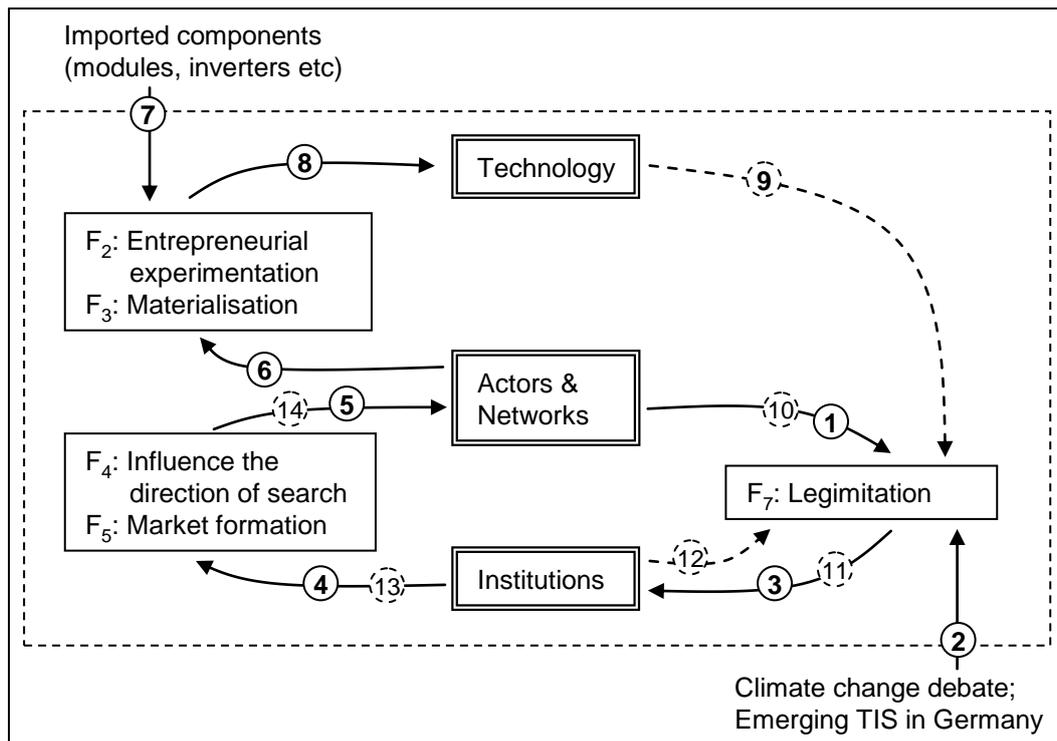


Figure 2: Example of functional and structural development (the solar cell TIS in Sweden)

From this framework follows that decision makers (management, policy, interest organisations) with an ambition to influence system dynamics may acquire an understanding of the micro level processes involved by capturing the strength and nature of each of the functions, how they interact with each other and influence the structural components, enlarging the TIS. They may then pinpoint any of these functions for system-building activities. To the extent that such intervention is successful, the structural elements of the TIS will alter, which then opens up for new opportunities for agency to intervene.

3. Legitimation and development of external economies in the formative phase

In this section, we will explore more deeply two of the functions in Table 1, ‘legitimation’ and ‘development of positive externalities’. This does not imply that we consider the other functions to be less important. Nor does it imply that other functions are not present in the descriptions, since, as pointed out above, the functions are closely linked and coupled in cause-effect chains. Rather, we ‘look into’ the system through the two selected functions. The focus on legitimation and external economies is chosen because of a perceived discrepancy between our empirical findings and the received literature.

First, whilst a number of studies on new technologies in general – and renewable energy technologies (see also the contribution by Agterbosch and Breukers in this special issue) and transport fuels in particular – underline the centrality of the process of legitimation,⁴² it is absent in much of the literature on ‘Policy and Innovation Systems’.⁴³ Perhaps acquiring legitimacy is particularly problematic in the energy and transport sectors, where incumbent technologies, actors and institutions have had decades (in some cases more than a century) to secure their positions as familiar and socially accepted. Incumbents are, indeed, powerful and highly organised and protect their investments – for which they receive very large direct and indirect subsidies – against discontinuous changes. Incumbents are, thus, not only hesitant towards adopting the new technologies,⁴⁴ but may also deliberately attempt to block the development of new TIS.⁴⁵ Much of the early efforts of an emerging TIS thus have to be spent on legitimation issues.

Second, as regards the ‘development of positive externalities’, we will take a particular angle by focussing on positive externalities that flow between *different* TIS. Conventional management and policy literature assumes a competitive relationship between technologies whereas our previous empirical work reveals a more complex picture including also strong complementarities. The focus on competition is prominent both in the management literature, with its focus on ‘competing designs’ in early phases,⁴⁶ and in the policy literature, which emphasise the value of regulatory frameworks leading to competition between technologies so as to secure that the most cost efficient solution is selected.⁴⁷ Shifting attention from competition only, to include finding common grounds on the basis of which advocates of various technologies may seek to collaborate could be particularly interesting in the context of climate change, which necessitates the parallel development of many TIS centred on different carbon neutral technologies.⁴⁸

3.1 ‘Legitimation’

Legitimacy is a matter of social acceptance and compliance with relevant institutions. It is necessary to attain legitimacy in order for resources to be mobilised, for demand to form and for actors in the new TIS to acquire political strength.⁴⁹ Thus, and as is widely acknowledged in previous research, legitimacy is a prerequisite for the formation of new industries and, we would add, new TIS.⁵⁰

Legitimacy is, however, not given but rather formed through conscious actions by various organisations and individuals in a socio-political process of legitimation, which incorporates

cognitive, normative as well as regulative aspects. The most commonly described strategy for industry legitimation is to conform to established institutions.⁵¹ For example, suppliers of ethanol fuel for cars may decide to advocate an increased use of low-ethanol blends for gasoline cars, which would imply regulative legitimation in terms of following the European Commission's fuel specifications for gasoline and normative legitimation in terms of allowing customers to remain true to their refuelling habits as well as their car preferences. However, in many cases of low-carbon innovation, existing institutions tend to block the development of new technological options.⁵² The strategic option (for firms) is, then, the most difficult one: to influence the institutional framework in order to achieve institutional alignment.⁵³ This may involve manipulation of established institutions (in order to bring them into conformity with the emerging TIS) or the establishment of new institutions.⁵⁴

In the earliest stage of the formative phase, legitimation mainly involves getting the technology accepted as a desirable and realistic alternative to incumbent substitutes.⁵⁵ In essence, legitimation then becomes “the politics of shaping expectations and of defining desirability”.⁵⁶ Before the components of the emerging TIS have been put in place, this is primarily done through “expert” legitimation built on technology assessments (TA) and “rational” arguments. As the proponents of the new TIS gain strength and political power, legitimation built on the familiarity, commitment and trust created by the accumulation of actors will increase in importance. In the following, we will discuss these two types of legitimation in more detail (for other aspects of legitimation, see the contribution by Agterbosch and Breukers in this special issue).

Early in the formative phase, when there is little experience of the technology, TA studies supply information about performance and potential. This is an “expert” legitimation based on “rational” arguments grounded in the knowledge base and problems articulated at a societal level. The role of assessment is, however, not unproblematic. It may cause genuine uncertainty for investors and policy makers and also create an opportunity for various actors (in different advocacy coalitions) to select assessment designs to legitimise or delegitimise a technology in order to serve their own “political” goals. We will discuss three sources of these problems.

First, *changing problem agendas* at the societal, or landscape, level may alter the weight of different performance criteria and the power of different arguments. Sandén and Jonasson, for instance, describe the shift of external driving forces for the development of alternative fuels

in Sweden from fear of oil depletion (1974 and 1985), through local air quality (1985-mid 1990s), to climate change and a return to the fear of oil depletion.⁵⁷ The shift in the 1980s had a dramatic effect on the legitimacy of methanol (from gasified feedstock), which was replaced by ethanol and methane as main alternatives. The second shift resulted in a move back towards gasified biomass (and towards hydrogen). What is legitimate, may, thus, shift rapidly in response to changing problem agendas.

Second, uncertainty may stem from *differences in the weight of various performance criteria* between actor groups, guided by diverging institutions. Since discontinuous technological change often implies substantial uncertainty with regards to future relevant systems-in-use and value networks,⁵⁸ it may be difficult for entrepreneurial actors to choose which institutional framework to adapt 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 was in vain. Potential users in the paper and pulp industry instead favoured technology features improving the quality of the pulp and the flexibility of the pulping process.⁵⁹

Third, even if there are shared performance criteria, assessments may give varying results due to *methodological choices* that are subtle and difficult to unmask for non-specialists. For this reason, assessments are often used in early institutional battles as a way to promote a specific technical solution. In the energy sector, this “politics of expectations and desirability” is, in particular, reflected in widely diverging statements of the potential of various renewable energy technologies.⁶⁰ In the Swedish wind power case, a potential of 20 TWh or more has been put forward by wind power proponents since the 1970s. However, a scrutiny of the major Swedish daily newspapers for articles that mention wind power reveals that more than 80 percent of these described the potential or actual wind power contribution as “small” or “smaller than some other electricity source”. These negative expectations on wind power, communicated through media, have not been counteracted by policy makers in a forceful way and this lack of a national vision for wind power has clearly contributed to a low legitimacy for wind power in the eyes of important stakeholders.⁶¹

The wind power potential is mostly described in terms of a comparison with nuclear power. This is symptomatic for the decades long Swedish “nuclear power trauma”, during which both wind power and biopower have been met with resistance from advocates of nuclear power.⁶²

A particularly telling example is an editorial in the leading (emphatically pro-nuclear) daily newspaper Dagens Nyheter which claimed that:

“Firewood can’t replace nuclear power... Biofuels can give us a marginal addition, but not even with maximum production can they, with respect to power, replace more than one nuclear power reactor.” (our translation)⁶³

“One nuclear power station” would imply a potential of approximately 5 TWh (as compared to actual output of biopower of 9 TWh in 2006). Some enquiries convey a larger but still very limited potential. For instance SOU (2001:77) suggests that the potential for biopower was about 12 TWh,⁶⁴ whereas other studies suggest a potential that is at least 22-27 TWh, as reported by Jacobsson.⁶⁵

An interesting aspect of the process of shaping expectations is in how opportunities are framed. For instance, in a Swedish government proposition it was argued that

“The Government has over a number of years supported biomass based CHP. In CHP, the biomass is used with a very high efficiency. The available heat base sets, however, an upper limit to how much power can be generated with such a high efficiency”.⁶⁶

Whilst technically correct, this citation portrays a picture of a potential that is tightly constrained by the district heating system and not the more appropriate image, in our view, of a vastly underutilised potential.⁶⁷

In sum, these examples indicate not only that what is considered relevant performance criteria may differ over time and vary between groups but also that besides apparent misinformation, there are many ways to frame and define a potential. This raises the question to what extent TA processes can be designed to increase transparency and reduce risk of misinformation. Despite efforts done in this direction, e.g. the ISO standards on Life Cycle Assessment methodology, the inherent political nature of TA and the impossibility to create universally relevant, acceptable as well as stable system boundaries and performance criteria, means that TA is probably doomed to remain a contested, although necessary, activity.

A first challenge for policy makers is, therefore, to make room for and listen to a variety of voices, arguments and interpretations. A second challenge is to develop the competence and independence to critically assess various attempts to shape expectations and normative legitimacy by developing an own vision of a new technology. A developed vision that is

ambitious enough may then underpin present and future policies (i.e. the institutional framework).⁶⁸

Legitimation is, however, not only built on arguments about expected performance derived from assessments but also on the accumulation of actors in a TIS, the experience of and familiarity with a new technology as well as trust in various actors supporting it. As the German experience of wind and solar power demonstrate, institutions are shaped in a process of cumulative causation where entry of firms (and other organisations) and the formation and strengthening of advocacy coalitions are additional constituent structural parts.⁶⁹ Legitimacy of a new technology is, therefore, not only a prerequisite for the formation of a TIS but also a result of that very same process.

Clearly, changing the regulative framework constitutes a challenge not easily mastered by individual entrepreneurs in early phases of the development of a TIS. Instead, institutional entrepreneurship is expected to be pursued by coalitions of actors “running in packs”,⁷⁰ in which firms are concerned not only with “...their own immediate proprietary tasks and transaction modes but also with...the overall social system”⁷¹. Yet, the very existence of such ‘packs’ presupposes a prior development of the TIS. In that development, ‘knowledge development’, although a prerequisite for system formation, can achieve little on its own. In particular, the formation of a market space that may allow for the building up of a critical mass of entrepreneurs who can form “packs” engaging in institutional entrepreneurship is of critical importance.⁷² Indeed, the clearest impact of the recent and very modest market formation programme for solar cells in Sweden (a few MW) has been the entry of firms and the formation of an industry association, which will act as a key node in an emerging advocacy coalition.⁷³

This space does not have to be large initially. The case of Germany is revealing in this respect. The stock of wind turbines in Germany in 1989 (end of formative phase) amounted to 221 machines with a capacity of 20 MW.⁷⁴ For solar power the stock in 1998 (end of formative phase) was 54 MW.⁷⁵ Similarly, there were only about 900 flexifuel vehicles in Sweden at the end of the formative phase in 2001.⁷⁶

The market space has, however, to be large enough to sustain enough number of actors to make up a critical mass. In the Swedish wind power case, the first demonstration programme in the 1980s only allowed for two MW turbines to be built and the first commercial market consisted of isolated investments by farmers and economic associations. This was not enough

to provide a market space to support early entrepreneurial initiatives. When investment subsidies were introduced in the early 1990s, the Swedish TIS was therefore weak and the market was handed over almost entirely to Danish firms. These did not have much interest in influencing the Swedish institutional framework to the benefit of further diffusion since there were other, rapidly expanding markets available (especially in Germany). Positive feed-backs failed, therefore, to materialise. This was, for instance, shown in the persistence of substantial weaknesses in municipal land-use planning and permits review processes. Due to the stunted early development of TIS structure, there was no strong advocacy coalition and, thus, no institutional entrepreneurship to speak of to handle this issue. It was left largely to policy makers to achieve institutional alignment through various top down instruments (such as the appointment of areas of national interest for wind power and guidelines for local land-use planning). At least so far, these have not been successful.⁷⁷

Actor entry is, thus, obviously central to the process of acquiring legitimacy, which is sometimes forgotten when regulative change is viewed as an exogenous process of ‘rational’ choices based on ‘rational’ assessments. For instance, the inclusion of politically powerful agricultural industry organisations in the ethanol TIS has been of great importance for achieving regulative change.⁷⁸ Moreover, for advocacy coalitions in the methane as well as ethanol systems, it has always been a prime target to enrol the Swedish car companies, not only to be able to materialise the technology (get vehicles) and learn from experimentation, but also and, perhaps more importantly, to make use of their political power. The launch of the Saab Biopower ethanol car in 2005, with a very visible advertising campaign, was a hallmark in the development of alternative fuels and signalled that the formative phase was definitely over.

Clearly, a bottom up evolutionary process to gain legitimacy can work if well orchestrated. Actor entry, growth of experience and normative and regulatory change may form virtuous circles enabling an expansion from small experiments to a system ready for take off into a growth phase. A major policy issue is, therefore, to complement conventional science and technology policy measures with policies leading to the formation of early and protected market spaces. These are needed, not only to enable learning and to maintain a variety of voices and arguments, but also to enable experienced and trust based legitimacy as well as the build up of “packs” of entrepreneurs and associated advocacy coalitions.

3.2 'Development of positive external economies'

The conventional view in management is that there is a competitive relationship between firms driving different designs within an emerging TIS (e.g. thin film versus crystalline silicon solar cells). In the literature, the notion of competing design is a central one and the formative phase is seen as a struggle for the selection of a dominant one.⁷⁹ Hence, the advocates of a specific design are seen to compete for resources and markets in order to be associated with a new dominant design.

In the climate policy literature, the notion of competition is shifted to the relationship between different emerging systems (e.g. solar power versus wind power). The predominance of neoclassical economics has led to an emphasis on achieving 'cost efficient' solutions which leads to the choice of policies such as tradable green certificates where different emerging TIS are pitted against each others.

A diverging view is one where each emerging TIS centred on carbon neutral technologies, may contribute to destabilise the energy 'regime',⁸⁰ by increasing both its own functionality and that of related TIS. As argued above, 'running in packs' is a strategy to increase functionality *within* a TIS. A similar notion of mutually beneficial co-evolution between several emerging TIS is based on relatedness that crosses apparent system boundaries.⁸¹

Marshall underlined the importance of economies that are external to the firm but internal to an industry (and location).⁸² Porter took that analysis a step further and incorporated also related industries into the realm in which external economies flow: "External economies ... often extend to related industries within the nation."⁸³ Related industries are "... those in which firms can coordinate or share activities in the value chain..."⁸⁴ In terms of our framework, relatedness is present if two or more emerging TIS share structural elements: actors and networks, technology or institutions.

Thus, we consider not only overlaps in terms knowledge spillovers,⁸⁵ but relatedness in terms of all structural components. To the extent that structural elements are shared, related TIS may mutually benefit from functions shaping these elements. The strengthening of one function in a TIS may, therefore stimulate the development of positive externalities that contribute to the build up of the structural components of another TIS.⁸⁶

The socio-technical overlaps between different TIS blur the distinction between them. Indeed, the choice of system boundary in terms of level of aggregation, number and types of

applications and value chains and geographical scope is somewhat arbitrary.⁸⁷ Ultimately, the choice depends on problem definition, i.e. what growth process that is to be studied.

However, this does not imply that the choice of boundary is unimportant. If we choose a narrow system boundary, such as ‘wheat ethanol production in Sweden’ or ‘wind power generation in Germany’ we face the risk of missing important feedback mechanisms (treated as merely exogenous influence). On the other hand, applying a wide system boundary, e.g. including all technologies within the groups of renewable electricity production and renewable fuels respectively, or the even wider group of all renewable energy systems, important feedback mechanisms may be missed due to lack of detail. A possible solution is to apply narrower and wider system boundaries in parallel and that is exactly what we do when we point out the existence of positive externalities flowing between what we initially treated as separate TISs.

The history of alternative fuels in Sweden provides a clear example of structural overlaps and positive externalities. Even after three decades of development, variety is still increasing. In this process of generating and upholding variety, we can identify a number of instances where benefits ‘spilled over’ from one TIS to another. Indeed, we are inclined to say that a dominant feature is that the alternatives have complemented each other in the quest for system transformation.

For example, wheat ethanol and wood ethanol share the same downstream technology (vehicles that can run on ethanol). The short term option wheat ethanol has been legitimated as a bridging technology towards wood ethanol that is considered to have larger potential. This shared legitimacy was important to get tax exemptions, i.e. changed regulation, which generated market creation and actor entry into the wheat ethanol system. On the other, hand wood ethanol has benefited in terms of resource mobilisation (R&D investments) from the lobbying (legitimation) activities for ethanol by agricultural organisations. To broaden the picture of spillovers, ethanol fuels, in general, benefited from the development of a methanol TIS, in an earlier period (1974-1985). The development of knowledge of alcohol engines enabled entrepreneurial experimentation with ethanol and a decreased tax enabled market formation for ethanol buses in the 1990s. A third example is the development of gasification technology to produce methanol from bioenergy and coal in the 1970s and 1980s, as well as the establishment of actors carrying the competence, that are now, some 25 years later, key components in TISs centred on other types of fuels produced from gasified biomass (DME, FT-diesel, biogas and hydrogen). These actor networks were also key to legitimate some of

these fuels which resulted in a resource mobilisation (funding of demonstration plants) in recent years. To give a final example, organisations promoting environmental cars by procurement and labelling in Stockholm, Göteborg and Malmö, once developed to promote electric vehicles, created the first real markets for ethanol and biogas cars, i.e. shared actors resulted in market formation.

These examples may give the impression that the externalities can be predicted in a straightforward way. However, the complex pattern of interacting functions across narrowly defined TIS boundaries may create surprising results. The somewhat unique development of biogas as an alternative fuel in the transport sector in Sweden is an example of this. A ‘search’ process in the municipality of Linköping was directed towards methane due to the expected extension of the natural gas grid and a successful experimentation with methane (natural gas) buses in Malmö in the 1980s. In the meantime, an experiment with locally available biogas (also a methane rich gas) was initiated. When the extension of the natural gas pipeline was stopped in 1991, biogas use was expanded. This expansion was made possible by two parallel developments. First, a continued development of natural gas buses in Malmö and Göteborg created ‘knowledge development’ and ‘materialisation’ of methane bus technology. Second, a national demonstration programme for biofuels in heavy vehicles was launched to investigate (and stimulate) ethanol use. This demonstration programme surprisingly came to supply financial resources also to biogas and enabled market formation. In turn, this helped create the actors, networks, knowledge and legitimacy needed to establish a biogas transport fuel TIS with the momentum required to generate new resources and market shares.

In attempts to realise their potential, the growth one TIS may, thus, pave the way for others. As is clearly seen in Germany, a legislative change promoting renewable energy technology (a feed-in law in 1991) that was initially driven by largely small scale hydropower advocates came in an unpredictable way, to benefit not only wind power in a massive way,⁸⁸ but also, with additional advocacy, solar power.⁸⁹ As Negro demonstrates, it also led to strategic investments by firms to develop a turn key capability in the biogas field which made possible the realisation of market opportunities created by the very same feed-in-law.⁹⁰ The initial efforts to align institutions to the need of small scale hydro power, thus, eventually came to benefit several other emerging TIS, all sharing a cognitive relatedness only.

The opportunity to share structural elements between what is normally seen as competing technologies, and competing TIS, open us for a further development of Van de Ven’s notion

of “running in packs” as described above.⁹¹ Such packs, we would argue, may consist not only of firms sharing an interest in a specific design (e.g. CIGS solar cells) or a single TIS (solar cells) but also across a range of TIS. As underlined above, the relatedness may not be in the technical dimension at all but it may suffice to have cognitive relatedness. For instance, solar cells and biopower share nothing but the notion of ‘renewable’. This is, however, a powerful relatedness that may be utilised to promote a vision of the future in which these two technologies jointly contribute to a plausible carbon neutral energy system (managing the politics of expectations).

Exploiting structural and functional overlaps clearly opens up for a more powerful ‘bottom-up’ process of institutional alignment and system growth than if each TIS is seen as self-contained. This has implications for both management and policy. For managers, it becomes essential to align the interests of advocates of several ‘competing designs’ and, in particular, to work *across* TIS by forming broader advocacy coalitions. Policy makers need to support such broader coalitions by selecting support schemes that do not pit various emerging TIS against each others in a misguided notion of efficiency that presupposes that the issue at stake is the selection of the most cost-efficient technology “from the shelf”. Instead, they should favour regulatory frameworks that enable a number of TIS to go through a formative phase in parallel, drawing strength from structural and functional overlaps, thus “filling the shelf” with a diverse set of technologies.⁹²

4. Conclusions, implications for decision makers and an idea for further research

The purpose of this paper was to go some way towards contributing to an improved understanding of the key micro level processes in the formation phase of a new technological innovation system (TIS) and to identify associated policy and management challenges. Empirically, we have used our previous work on the development of renewable electricity technologies and transportation fuels in Sweden and Germany. We proposed an extension from a structural focus on dynamics to a combined structural-functional perspective, where a number of key processes – “functions” – driving the development, diffusion and utilisation of new technology were identified. We discussed how these functions are shaped by both endogenous and exogenous factors and how they, in turn, shape the structural evolution of the TIS.

Whereas all these functions may guide decision makers seeking to engage in system building activities, we focused our analysis on two of the functions: ‘legitimation’ and ‘development of positive externalities’ where the angle to the latter was overlaps between different narrowly defined TISs. For the former, we pointed to the problematic role of technology assessment studies in ‘the politics of expectations’ and in shaping legitimacy. While necessary to reduce uncertainty, they also constitute a source of uncertainty and contain much opportunity to shape expectations in ways that are subtle and difficult to unmask. This is particularly problematic for immature technologies that face entrenched incumbents with a superior access to funding, media and politicians. Decision makers therefore need to not only preserve a variety of voices but also develop their own and independent competence to critically assess attempts to shape expectations and to form an own vision of the future of a specific technology.

The shaping of expectations is part and parcel of a bottom-up strategy of system building where ‘packs of entrepreneurs’ and others work to improve legitimacy, influence the direction of search of other firms, shape institutions and form markets. Yet, the existence of such ‘packs’ presupposes an initial market. It does not have to be large initially but is required for a process of cumulative causation to eventually unfold. Policy makers, therefore, have to form a regulatory framework that provides a smaller ‘protected space’ for ‘packs’ to emerge in, long before the technology is competitive in the market. Market formation is, thus, not only the effect of the development of new technologies but also a prerequisite for it.

To the extent that there are structural overlaps between different TISs, they may mutually benefit from functions strengthening these elements. In various ways, the achievement and growth of one TIS may pave the way for others – positive external economies may flow between different TISs. As shown in the case of biofuels in Sweden, positive interaction between TISs does not have to be in any way intended and part of strategy, but sometimes happens unexpectedly. However, exploiting overlaps opens up for a more powerful “bottom-up” process of system growth than if each TIS is seen as self-contained. Managers and policy makers may enable this by going against conventional wisdom, forming broad based advocacy coalitions (management) and by fostering several TIS in parallel (policy).

The framework presented has proved its usefulness but additional work is required to develop it further. We will point to one line of direction for improvement. In section 2, we argued that structural and functional dynamics were intertwined in the formative phase. For example, the

function ‘guide the direction of search’ is closely linked to firm entry and ‘legitimation’ often involves shaping the institutional framework. Yet, our understanding of these feed back loops needs to be developed further. This applies, in particular, to the relation between functions and the formation of various types of networks. Entry of firms and other organisations upstream is a prerequisite for but does not automatically lead to formation of learning networks or political networks. Nor does market formation downstream automatically lead to the formation of user-supplier networks in which knowledge is exchanged beyond what is covered by a transaction. Hence, a limitation of our framework is that we do not fully capture the key processes that lead to network formation. In what follows, we will point at a line of argument which may deal with this weakness.

Arguably, networks are formed as and when the actors in the system realise the potential of the collective dimension of innovation systems. This dimension, as a whole, is captured in the seventh function, ‘development of positive external economies’. Some of these are mediated through markets (e.g. pecuniary external economies stemming from a further division of labour) whereas others are connected to the functioning of networks, and therefore, flow only in as far as firms commit resources to investing in forming and maintaining networks. Hence, in order to interact, firms and other actors need to identify themselves as part of a system, see the common problems and opportunities they face and the value of collective action.⁹³ This was, for example, the case in the example of the Swedish solar cell TIS, as described in section 2, where some firms saw the need for an organisation that could manage such action. In essence, therefore, network formation reflects the consciousness and practical realisation of parts of the collective dimension of the innovation and diffusion process. Without such a consciousness, user-supplier relationships will be arms-length, university-industry relationships may not develop and political networks not formed.

5. Notes and References

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³ The cases are documented in: A. Bergek, ‘Levelling the playing field? The influence of national wind power instruments on local land-use planning practices in a Swedish county’, paper under review by *Energy Policy*; A. Bergek & S. Jacobsson, ‘The Emergence of a Growth Industry: A Comparative Analysis of the German, Dutch and Swedish Wind Turbine Industries’, in: S. Metcalfe & U. Cantner (eds), *Change, Transformation and Development* (Heidelberg, Physica-Verlag, 2003), pp. 197-227; S. Jacobsson, ‘The emergence and growth of a ‘biopower’ innovation system in Sweden’, forthcoming in *Energy Policy*; S. Jacobsson, B. A. Sandén & L.

Bångens, 'Transforming the energy system - the evolution of the German technological system for solar cells', *Technology Analysis and Strategic Management*, 16(1), 2004, pp. 3-30; L. Palmblad, S. Jacobsson, M. Hall & B. A. Sandén, 'Dynamics of the Swedish PV innovation system – the impact of a recent market formation programme', paper presented at the 21st European Photovoltaic Solar Energy Conference, Dresden 4-8 September, 2006; B. A. Sandén & K. M. Jonasson, 'Variety creation, growth and selection dynamics in the early phases of a technological transition: The development of alternative transport fuels in Sweden 1974-2004', *ESA report 2005:13* (Göteborg, Chalmers University of Technology, 2005).

⁴ Although the system concept may suggest collective and coordinated action, an innovation system is primarily an analytical construct. That we use the notion of an "overall function" does not imply that all actors in a particular system exist for the purpose of serving that function or are directed by that function. Actors do not necessarily share the same goal, and even if they do, they do not have to be working together consciously towards it (although some may be). Indeed, conflicts and tensions are part and parcel of the dynamics of innovation systems. Nor does it imply that the system in focus has to exist in reality as a full-fledged one. As will be evident from this paper, it may be emerging with very weak interaction between components. Even in a more developed innovation system, moreover, the interaction between components may very well be unplanned and unintentional rather than deliberate.

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⁶ B. Carlsson & R. Stankiewicz, 'On the nature, function, and composition of technological systems', *Journal of Evolutionary Economics*, 1(2), 1991, pp. 93-118; S. Jacobsson & A. Johnson, 'The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research', *Energy Policy*, 28, 2000, pp. 625-640.

⁷ Wenk & Kuehn, *op. cit.*, Ref. 5.

⁸ A. Bergek, *Shaping and Exploiting Technological Opportunities: The Case of Renewable Energy Technology in Sweden*, Ph.D. Thesis (Göteborg, Department of Industrial Dynamics, Chalmers University of Technology, 2002); Carlsson & Stankiewicz, *op. cit.*, Ref. 6; R. Galli & M. Teubal, 'Paradigmatic Shifts in National Innovation Systems', in C. Edquist (ed.), *Systems of Innovation* (London, Pinter, 1997), pp. 342-370.

⁹ F. W. Geels, 'From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory', *Research Policy*, 33(6-7), 2004, pp. 897-920; Hughes, 1983, *op. cit.*, Ref. 5; Sandén & Jonasson, *op.cit.*, Ref.3.

¹⁰ Wenk & Kuehn, *op. cit.*, Ref. 5.

¹¹ S. S. Das & A. H. Van de Ven, 'Competing with New Product Technologies: A Process Model of Strategy', *Management Science*, 46(10), 2000, pp. 1300-1316; E. T. Layton, 'Technology as knowledge', *Technology and Culture*, 15(1), 1974, pp. 31-41.

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¹⁵ M. Fransman, *The Market and Beyond* (Cambridge, Cambridge University Press, 1990).

¹⁶ P. A. David, 'Path dependence: putting the past into the future of economics', *Institute for Mathematical Studies in the Social Sciences Technical Report 533*, Stanford University, 1988.

¹⁷ W. E. Bijker, *Of bicycles, bakelites, and bulbs: Toward a theory of sociotechnical change* (Cambridge, MIT Press, 1995); F. Geels & B. Raven, 'Non-linearity and expectations in niche-development trajectories: Ups and downs in Dutch biogas development (1973-2003)', 2006, forthcoming in *Technology Analysis and Strategic Management*.

¹⁸ G. Dosi, 'Technological paradigms and technological trajectories', *Research Policy*, 11, 1982, pp. 147-162.

¹⁹ H. van Lente, 'Promising Technology', in A. Rip (ed.), *The Dynamics of Expectations in Technological Development* (Twente, Universiteit Twente, 1993).

²⁰ B. Carlsson & S. Jacobsson, 'Technological Systems and Economic Performance: the Diffusion of Factory Automation in Sweden', in D. Foray & C. Freeman (eds), *Technology and the Wealth of Nations* (London and New York, Pinter Publishers, 1993), pp. 77-94; Geels & Raven, *op. cit.*, Ref. 17.

²¹ P. A. Sabatier, 'The advocacy coalition framework: revisions and relevance for Europe', *Journal of European Public Policy*, 5, 1998, pp 98-130.

- ²² The development of a technological niche in the literature on Strategic Niche Management corresponds to an early part of the formative phase.
- ²³ A. Van de Ven & R. Garud, 'A Framework for Understanding the Emergence of New Industries, Research on Technological Innovation', *Management and Society*, 4, 1989, pp. 195-225.
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- ²⁶ Carlsson & Jacobsson, *op. cit.*, Ref. 24; M. Porter, 'Clusters and Competition. New agendas for companies, governments and institutions', in M. Porter. (ed.), *On Competition* (Boston, A Harvard Business Review Book, 1998), pp 197-287.
- ²⁷ G. Myrdal, *Economic Theory and Underdeveloped Regions* (London, Ducksworth Pubs., 1957). Often, the shift to a growth phase is triggered by external events.
- ²⁸ For lists on positive feed-back mechanisms from technology adoption in the energy sector and the solar cell industry, respectively, see Sandén & Azar, *op.cit.*, Ref. 2 and B. A. Sandén, 'The economic and institutional rationale of PV subsidies', *Solar Energy*, 78, 2005, pp. 137-146. However, not only virtuous but also vicious circles are possible (S. O. Negro, M. P. Hekkert & R. E. Smits, 'Explaining the failure of the Dutch innovation system for biomass digestion – A functional analysis', *Energy Policy*, 35(2), 2007, pp. 925-938).
- ²⁹ The "transition" between an early formative phase and a phase of resilience roughly corresponds to that described by Geels (*op. cit.*, Ref. 24), in which a "niche" emerges and grows within a (changing) regime or forms the basis of a new regime.
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- ³¹ See A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark & A. Rickne, 'Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis', forthcoming in *Research Policy*.
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- ³³ This function also covers the mechanisms influencing the direction of search *within* the TIS, in terms of different competing technologies, applications, markets, business models etc.
- ³⁴ Bergek et al., *op. cit.*, Ref. 31.
- ³⁵ See, e.g., Bergek & Jacobsson, *op. cit.*, Ref. 3; Johnson & Jacobsson, *op. cit.*, Ref. 30.
- ³⁶ Bergek et al., *op. cit.*, Ref. 31.
- ³⁷ Geels, *op. cit.*, Ref. 24.
- ³⁸ The whole notion of functions was developed to handle an integration of technology-specific and more general influencing factors: "These factors may be fully technology specific, but may influence several technological systems simultaneously. Hence, they can be derived from a system perspective using different units of analysis: technology, industry, nation." (Johnson & Jacobsson, *op. cit.*, Ref. 30, p. 93).
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- ⁴⁶ J. M. Utterback, *Mastering the dynamics of innovation* (Boston, Harvard Business School Press, 1994).
- ⁴⁷ E. g. K. Alfsen & G. Eskeland, 'A Broader palette: The role of technology in climate policy', *Report to the Expert Group for Environmental Studies 2007:1* (Stockholm, Ministry of Finance, 2007).
- ⁴⁸ Stern, *op. cit.*, Ref 1. The pattern of legitimation and development of positive externalities are likely to change as the systems grow and mature. However our scope in this paper does not extend beyond the formative phase where institutions are formed by legitimation and where systemic overlaps, or positive externalities, start to appear.
- ⁴⁹ E.g. Aldrich & Fiol, *op. cit.*, Ref. 42.
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- ⁵³ Oliver, *op. cit.*, Ref. 51; L. G. Zucker, 'Institutional Theories of Organization', *Annual Review of Sociology*, 13, 1987, pp. 443-464.
- ⁵⁴ Cf. B. E. Ashforth & B. W. Gibbs, 'The Double-Edge of Organizational Legitimacy', *Organization Science*, 1(2), 1990, p. 177-194. Oliver, *op.cit.*, Ref 51. Suchman, *op. cit.*, Ref. 51. M. A. Zimmerman & G. J. F. Zeitz, 'Beyond survival: Achieving new venture growth by building legitimacy', *Academy of Management Review*, 27(3), 2002, p. 414-431.
- ⁵⁵ This refers primarily to normative and cognitive institutional alignment. Influencing the regulatory framework usually requires some legitimacy already to be in place.
- ⁵⁶ Rightly so, Strategic Niche Management emphasise this theme by identifying one of three key processes as "voicing and shaping expectations" (Raven, *op. cit.*, Ref. 40). For the role of expectations in the case of gasified biomass in the Netherlands, see: Negro et al., *op. cit.*, Ref. 28.
- ⁵⁷ Sandén & Jonasson, *op. cit.*, Ref. 3
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- ⁶⁰ The selection of timeframe is particularly important and is often done in an arbitrary or even seductive way and ultimate physical constraints are often confused with short or medium term technical, economic or political constraints. K. M. Hillman and B. A. Sandén, 'Time and scale in life cycle assessment: The case of fuel choice in the transport sector'. *International Journal of Alternative Propulsion*, 2007, (in press).
- ⁶¹ Bergek, *op. cit.*, Ref. 3.
- ⁶² This trauma has been created by a pressure to dismantle the nuclear power stations which run with a very low marginal cost and replacing that power production by new plants with a higher average cost.
- ⁶³ Dagens Nyheter (1996): Ved kan inte ersätta kärnkraft. Biobränslen kan ersätta annan energi men bara marginellt bidra till elproduktion, October 17th.
- ⁶⁴ SOU (2001:77): *Handel med certifikat. Ett nytt sätt att främja el från förnybara energikällor* (Stockholm, Statens Offentliga Utredningar, 2001).
- ⁶⁵ Jacobsson, *op. cit.*, Ref. 3.
- ⁶⁶ Prop. 2001/02:143: Samverkan för en trygg, effektiv och miljövänlig energiförsörjning ("Collaboration for a safe, efficient and environment-friendly energy supply"), Government bill, March 2002.
- ⁶⁷ Jacobsson, *op. cit.*, Ref. 3.
- ⁶⁸ Moderate expectations may keep some actors from entering the TIS. In the case of wind power, a national planning target of 10 TWh of wind power by 2015 was set by the government in 2002. Although this target is perceived to be reasonable by several types of actors, the corresponding county targets (which only amount to 4 TWh in total) seem to have been set on a too low level to facilitate wind power planning on regional and local levels (Bergek, *op. cit.*, Ref. 3). On the other hand, grand expectations could mobilise delegitimation efforts by threatened incumbents (Jacobsson & Bergek, *op. cit.*, Ref. 32).

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- ⁷⁰ Aldrich & Fiol, *op. cit.*, Ref. 42; Van de Ven, *op. cit.*, Ref. 25.
- ⁷¹ Van de Ven, *op. cit.*, Ref. 25, p. 223.
- ⁷² Kemp et al., *op. cit.*, Ref. 25.
- ⁷³ Palmblad et al., *op. cit.*, Ref. 3.
- ⁷⁴ Bergek & Jacobsson, *op. cit.*, Ref. 3.
- ⁷⁵ Jacobsson et al., *op. cit.*, Ref. 3.
- ⁷⁶ Sandén & Jonasson, *op. cit.*, Ref. 3.
- ⁷⁷ Bergek, *op. cit.*, Ref. 3.
- ⁷⁸ Sandén & Jonasson, *op. cit.*, Ref. 3.
- ⁷⁹ E.g. Utterback, *op. cit.*, Ref. 46.
- ⁸⁰ Raven, *op. cit.*, Ref. 40.
- ⁸¹ For a related observation of symbiosis and predator-prey relationships between technologies besides pure competition see C. W. I. Pistorius & J. M. Utterback, 'Multi-mode interaction among technologies', *Research Policy*, 26, 1997, pp. 67-84.
- ⁸² A. Marshall, *Principles of Economics* (8th ed) (London, Macmillan and Company Ltd., 1890).
- ⁸³ M. Porter, *The Competitive Advantage of nations* (London, McMillan, 1990), p. 144.
- ⁸⁴ *Ibid*, p. 105.
- ⁸⁵ See, e.g. G. Eliasson, 'General purpose technologies, industrial competence and economic growth', in B. Carlsson (ed.), *Technological systems and Industrial Dynamics* (Boston, Kluwer Press, 1997), pp. 201-253.
- ⁸⁶ A structural overlap could, of course, also imply the risk that a bad reputation for one technology spills over and generates negative externalities for a related technology. See the example of nuclear power and the discussion on reputation spill-over in B. A. Sandén, 'Technology path assessment for sustainable technology development.' *Innovation: management, policy and practice*, 6, 2004, pp. 316-330.
- ⁸⁷ We need to decide the level of aggregation in terms of technology (e.g. solar electricity, solar cells, thin film solar cells, CIGS thin-film solar cells, etc), the range of applications and value chains to include (e.g. ethanol production vs. ethanol used as transportation fuel vs. ethanol from forestry vs. ethanol from forestry used as transportation fuel), and finally a geographical boundary (World, Europe, Sweden, county of Sweden) (cf. Bergek et al., *op. cit.*, Ref. 31).
- ⁸⁸ Bergek & Jacobsson, *op. cit.*, Ref. 3.
- ⁸⁹ Jacobsson & Lauber, *op. cit.*, Ref. 59.
- ⁹⁰ S. O. Negro, *Dynamics of Technological Innovation Systems: The Case of Biomass Energy* (Utrecht, Copernicus Institute for Sustainable Development and Innovation, 2007).
- ⁹¹ Van de Ven, *op. cit.*, Ref. 25.
- ⁹² This variety of course has the additional advantage of handling uncertainties from a societal level and building a response capacity. As and when a large scale deployment is deemed desirable, the capabilities and structures are there to respond, cutting lead time in the transformation of the energy sector.
- ⁹³ R. C. Turner, *A Framework for Cluster-Based Economic Development Policies* (New York, The Nelson A. Rockefeller Institute of Government, 2001).