SYSTEMS OF INNOVATION AS A CONCEPTUAL FRAMEWORK FOR STUDYING THE EMERGENCE OF NATIONAL RENEWABLE ENERGY INDUSTRIES

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Abstract: This conceptual paper articulates an analytical framework, which collectively borrows from the concepts of Sectoral, National and Technological Innovation Systems, for examining the prospects for the emergence of renewable energy industries in a given country. In order to examine the dynamics within the national energy system under consideration, a list of system functions has also been compiled from the literature. It is believed that the adoption of such a functions approach has the potential to enhance our understanding of the process of, and drivers behind, the emergence and transformation of energy innovation systems. Towards the end of this paper, other theoretical concepts are acknowledged as also relevant for investigating the potential establishment of renewable energy industries. While every theoretical approach has its strengths and weaknesses, an effort has been made in this paper to justify the adoption of a suitable framework that is based on the systems of innovation approach.

Keywords: *innovation systems; functional analysis; sustainable innovation; renewable energy policy*

INTRODUCTION

The process of changing from fossil fuel-based energy systems to more sustainable ones can be seen as a long-term process of technological change, the analysis of which is the prime focus of innovation studies. When observing the policy-making front however, it appears that innovation and sustainability issues have, until quite recently, usually been addressed through separate policy regimes that are based on distinct rationales for policy intervention. Among the notable scholarly efforts to explicitly bring these two regimes closer was a report by Foxon (2003). This report, commissioned by the Carbon Trust, aimed to analyse drivers and barriers to low-carbon innovation, and the broad implications of this for public policy support in the United Kingdom (UK). The author subsequently became the co-ordinator and lead researcher for a project entitled 'Policy Drivers and Barriers for Sustainable Innovation' under the ESRC Sustainable Technology Programme (2004-2006). Another

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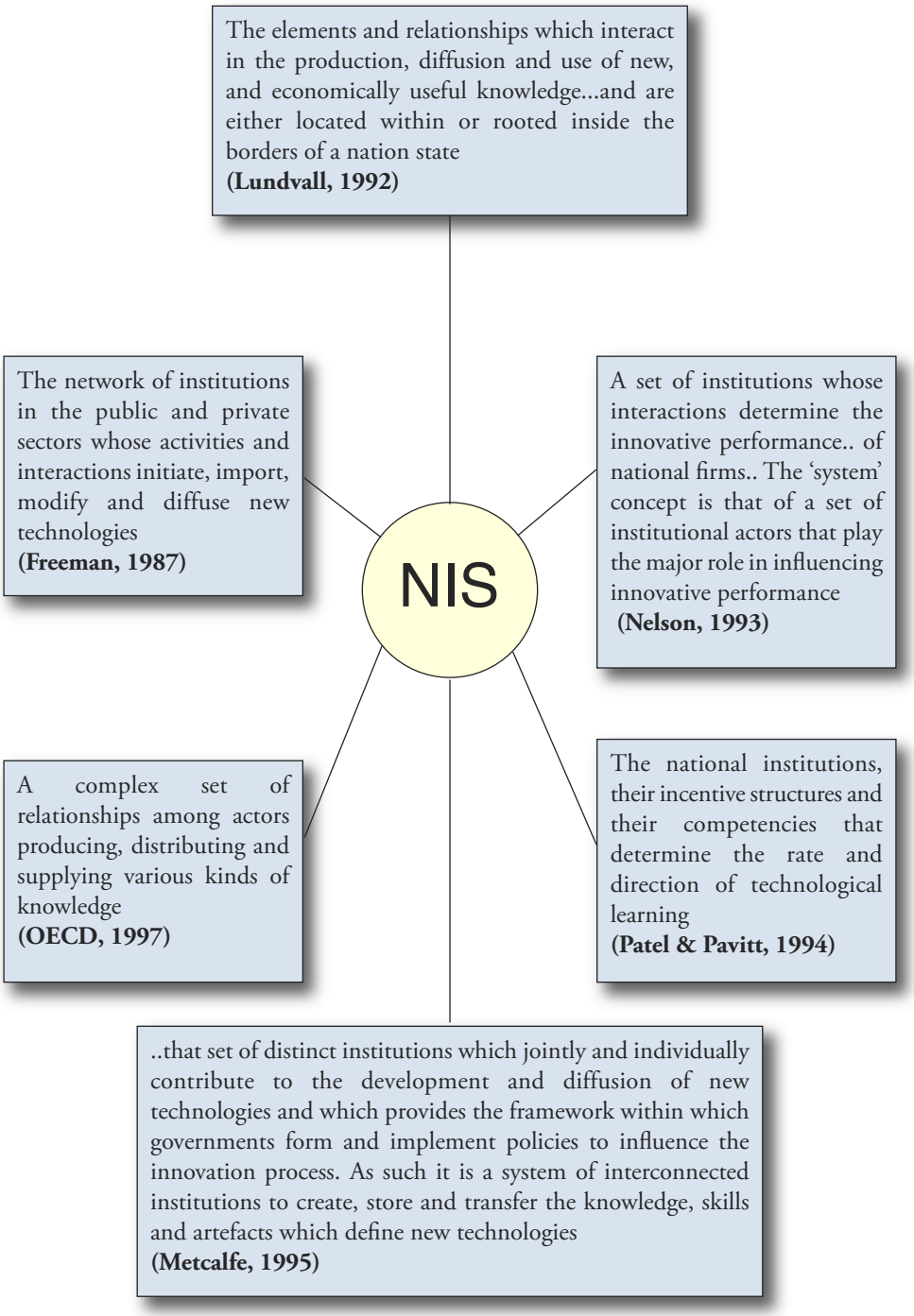
related major research activity was undertaken as part of a Dutch programme entitled 'Knowledge Creation for Sustainable Innovation', which focused more on the human and organisational dimensions of the innovation process (Jorna, 2006). Among the findings of the UK-ESRC programme was a recognition of the need to: (1) stimulate the development of a sustainable innovation policy regime, through bringing together innovation and environmental policy regimes; and (2) apply systems thinking to promote a transition to sustainability. Moreover, the programme stressed the need for further theoretical development and more empirical work through conducting a wider range of case study analyses (Foxon and Pearson, 2008). In this regard, this paper aims to address these needs as it articulates and justifies a system of innovation (SI) – based theoretical framework for studying the prospects for establishing national renewable energy industries, its ultimate premise being the provision of insights in terms of policy-making implications for promoting sustainable innovation within such countries.

To begin with, one needs to highlight the importance of adopting theoretical (i.e. conceptual) frameworks for analysing and making sense of the findings of empirical research endeavours. Hamel et al. (1993) and Yin (1981) commented that the reliance on theoretical concepts in order to guide the design of academic research is one of the most important elements for the successful completion of such research. Robson (2002) further explained that conceptual frameworks are important in helping us determine which features and relationships are likely to be of significance, and consequently, which data need to be collected and analysed. Since there have only been a limited number of studies about sustainable energy which have drawn upon the theoretical concepts that have recently been articulated within the realm of innovation studies (Foxon et al., 2005; Foxon and Pearson, 2008), it was decided to base this paper on the dominant theoretical concepts relating to the systems of innovation (SI). In essence, adopting an SI perspective allows a transition of the rationale for policy intervention from the typically limited approach of 'market failures' to a more appropriate 'systemic failures' one.

INTRODUCING THE CONCEPT OF SECTORAL INNOVATION SYSTEMS

Since the focus of this paper is on renewable energy industries, the concept of Sectoral Innovation Systems (SIS) may appear as a relevant and appealing framework. This concept followed – to some extent – the innovation system approach which was articulated initially at the national level (i.e. NIS) in the mid-1980s by Freeman (1987) and Lundvall (1988), who were then followed by others (e.g. Edquist, 1997; Nelson, 1993; OECD, 1997; Patel and Pavitt, 1994). Early NIS scholars however, including Freeman and Lundvall themselves, admitted that the idea behind NIS actually goes back to the notion of 'The National System of Political Economy' that was proposed by the famous German economist Friedrich List (1789–1846). The NIS concept is essentially still emerging and its definition varies considerably, depending on the characteristics of the system being considered. Figure 1 shows a range of the most cited NIS definitions that have been proposed within the innovation literature.

Figure 1: Different Definitions of the NIS Concept



Since the introduction of the NIS concept, there has been a considerable debate in the literature as to whether the 'nation state' is an appropriate level of analysis for innovation, or whether other scales should be considered. Consequently, a number of scholars have also suggested different approaches to the concept of innovation systems from a local perspective (Acs et al., 1996; Mytelka, 2000; OECD, 1999), as well as from regional (Boekema et al., 2000; Braczyk et al., 1998; Cooke et al., 1997) and sectoral viewpoints (i.e. SIS) as a response to globalisation. Generally speaking, the innovation system approach has changed the analytical perspective about innovation from the traditional linear models (e.g. that of a 'technology push' and 'market pull' or of 'basic research – applied research – development – diffusion') to a systemic view of interaction among different actors (Edquist, 2005).

The work of Malerba (2002; 2004; 2005) represents some of the pioneering endeavours that have introduced the concept of SIS. From this work, it appears that the SIS concept is based on a wide range of theoretically-rich intellectual traditions and contributions, such as:

Change and Transformation in Sectors

The first group of contributions to which SIS is related has underlined the significance of change and transformation in all sectors. Since sectors change over time, there is a need to consider their dynamics, emergence and transformation. It appears that emphasis on such factors is most evident in the literature related to the industry life-cycle (e.g. Klepper, 1996; Utterback, 1994).

Links, Interdependencies and Sectoral Boundaries

This academic field has placed a considerable emphasis upon links, interdependencies and, consequently, sectoral boundaries. It is argued that the sectoral boundaries are not fixed (i.e. they have a tendency to change over time) and that these boundaries should include links and interdependencies among related industries and services. It is such dynamic complementarities among activities and artefacts that provide a momentum and mechanism for growth and innovation. These claims seem to largely be in accord with the notion of development blocks (Dahmén, 1971; 1989), which is linked with the argument that a potential for dynamism and industrial development could be attributed to a series of complementarities and structural factors that are closely interconnected and interdependent.

Sectoral Taxonomies

A frequently used classification of industrial sectors in studies of innovation is the so-called 'Pavitt taxonomy' (Pavitt, 1984), which seems more inductive than the 'high/medium/low technology taxonomy' originally used by the Organisation for Economic Co-operation and Development (OECD). Subsequently, Soete and Miozzo (1989) modified the Pavitt taxonomy to include the service sector. Another complementary approach to the early Pavitt taxonomy, focusing more directly on the knowledge bases underlying innovation in different sectors, was initially proposed by Pavitt himself (1994) and later emphasised by Marsili (2001). Such approaches have attempted to provide a conceptual framework that links diverse characteristics of industrial sectors into plausible categories. Nonetheless, it is often argued that these groupings are

not analytically conclusive. For example, many low-technology industries coincide closely with Pavitt's class of 'supplier dominated sectors' as their firms rely on purchasing embodied innovative technologies for improved productivity (Robertson et al., 2009). Out of Pavitt's sectoral groupings, renewable energy technologies could arguably fit the 'Science-Based General' (i.e. not really services-orientated) classification, along with electronics. An alternative approach to the Pavitt taxonomy is the distinction between 'Schumpeter Mark I and Mark II Technological Regimes', which places an emphasis on differences in market structure and industrial dynamics among actors (see Breschi et al., 2000; Malerba and Orsenigo, 1996). Schumpeter Mark I can be characterised by technological ease of entry and the fundamental role played by entrepreneurs and new firms in innovative activities. On the other hand, Schumpeter Mark II is characterised by the dominance of large firms and the existence of relevant barriers to entry for new innovators. The proponents of this approach recognise that, based on an industry life-cycle view, the Mark I pattern of innovative activities may turn into Mark II (e.g. Klepper, 1996). They also acknowledge that the labels 'Schumpeter Mark I and Mark II' were originally introduced by Nelson and Winter (1982) in order to characterise synthetically the theoretical models of innovation activities proposed by Schumpeter in, respectively, *The Theory of Economic Development* (1934) and *Capitalism, Socialism and Democracy* (1942).

In effect, such sectoral taxonomies have attempted to provide conceptual frameworks that place diverse characteristics of industrial sectors into plausible groupings. The underlying assumption of these contributions is that innovation and technological change are largely affected by the sector in which they take place (Breschi and Malerba, 2005). In this regard, OECD (2005) stated that "Innovation processes differ greatly from sector to sector in terms of development, rate of technological change, linkages and access to knowledge, as well as in terms of organisational structures and institutional factors. Some sectors are characterised by rapid change and radical innovations, others by smaller, incremental changes. In high-technology sectors, R&D plays a central role in innovation activities, while other sectors rely to a greater degree on the adoption of knowledge and technology. Differences in innovation activity across sectors (e.g. whether mainly incremental or radical innovations) also place different demands on the organisational structure of firms, and institutional factors such as regulations and intellectual property rights can vary greatly in their role and importance" (p. 37). Based on these ideas, the SIS framework could potentially provide a methodology for the analysis and comparison of sectors in terms of sectoral transformations, structure and the boundaries of sectors (Malerba, 2005).

Evolutionary Theory

Evolutionary theories emerged as a reaction to the somewhat static neo-classical economic theories, which simplify the characterisation of economic processes, firms and the way these firms use knowledge (Duysters, 1995). Instead of the traditional view that technical change and innovation are a direct result of a desire to maximise profits, Nelson and Winter (1982) suggest that innovation can be understood as an evolutionary process. It is argued that not only are non-profit-making actors involved in innovation, but they can also interact with profit-orientated ones in complex ways when pursuing innovation and learning (i.e. formal and informal knowledge produc-

tion). In effect, evolutionary innovation is a relatively new economic approach that was roughly modelled on Darwinian concepts in biology with regard to variation and selection (see Table 1). Evolutionary economics takes variation and selection as a central mechanism for explaining innovation and technological development.

Table 1: Evolutionary Process in Biology and Innovation Studies (based on Edquist, 1997)

Feature	In Biology	In Innovation
Entities that exist and reproduce	Genotypes	Set-ups of technologies and organisational forms
Mechanisms that introduce novelties (create variation)	Mutations	Innovations
Mechanisms that select among the entities present in the system, leading to an increase in the relative importance of some and a reduction in that of others	Natural selection	Market selection and non-market selection (institutions, including rules and strategies within firms, governmental regulations and public technology policies)

Apparently, since neo-classical theories view an economy as in equilibrium configuration that undergoes well-anticipated change, it is assumed that good economic performance is judged in terms of how close it is to a theoretical optimum. On the other hand, the evolutionary theory of technical change places processes, dynamics and transformations at the centre of the analysis. Knowledge produced through 'learning-by-interacting' is also reported to be a key element in the change that takes place within economic systems (Dosi and Nelson, 1994; Hodgson, 1993; Metcalfe, 1998; Saviotti and Metcalfe, 1991).

Innovation System Approach

The SI approach draws much from evolutionary theory, and generally speaking, views innovation as an interactive process on the part of a wide range of actors (including firms and other organisations). It is argued that actors do not innovate in isolation, thus innovation is regarded as a collective process. This is very different from traditional indicators of technological change such as labour productivity, growth of turnover, product differentiation, etc. The OECD (1997), when it introduced the concept of NIS, suggested that it could offer new rationales for government technology policies. Government policies and intervention, based on neo-classical economics, typically focused on 'market failures'. However, studies of NISs make it possible to identify 'systemic failures' that could impede the innovative performance of a nation. The SIS concept complements some of the underlying arguments behind the NIS concept,

which has focused primarily on national boundaries, non-firm organisations and institutions. It is further conceded, however, that there are many sectors in which knowledge inputs are effectively exchanged at a distance due to convergent technologies or perhaps contain tightly defined production processes. In the latter cases, globalisation causes these sectors to organise themselves within a dimension where individual nations are irrelevant. Therefore, it might be more appropriate to speak of sectoral systems of innovation that span continents, because national boundaries are not always the most suitable ones for analysing the structure, actors and dynamics of these systems.

The Concept of the Technological System

The notion of the Technological Innovation System (TIS) was originally defined by Carlsson and Stankiewicz (1991) as:

> …a dynamic network of agents interacting in a specific technology area under a particular institutional infrastructure and involved in the generation, diffusion and utilisation of technology (p. 94).

The technology-specific feature of a TIS makes this concept attractive when the focus of enquiry is competition between various technologies to perform a certain function (say, for example, to supply energy). The proponents of the TIS believe that this concept belongs to the SI approach, despite the fact that it did not initially use language associated with SI (Carlsson and Stankiewicz, 1995). Carlsson et al. (2002a), however, maintain that it is possible to have several technological systems within a country. This makes the TIS somewhat different from the NIS approach. Moreover, it is argued that technological systems can evolve over time (i.e. the number and types of actors, institutions, relationships among them, etc. may vary over time). The TIS, like the SIS, also seems to support the notion of 'design space' which essentially refers to the competence

Table 2: Defining the TIS Concept in Three Dimensions (Based on Carlsson and Eliasson, 2003)

Cognitive Dimension	This defines the clustering of technologies (i.e. design space) that results in a new set of technological possibilities.
Organisational & Institutional Dimension	This captures the interactions in the network of actors engaged in the creation of these technologies. These networks are typically made up of a variety of actors, ranging from firms and universities to other actors within the private and public sectors.
Economic Dimension	This refers to those specific actors and their functional competencies that turn technological possibilities embedded in design spaces into business opportunities that could, in turn, propel economic growth. The greater the receiver competence (Eliasson, 1990), or absorptive capacity (Cohen and Levinthal, 1990) in the system, the greater the chance that such business opportunities will be identified.

base which actors draw upon within a particular sector (Stankiewicz, 2000). In a recent attempt to conceptualise the notion of TIS, Carlsson and Eliasson (2003) defined it in three dimensions (summarised in Table 2).

Evidently, a technological system can be seen as being made up of three main elements: actors and their competencies (technical and otherwise), networks and, finally, institutions. It is perhaps worthwhile here to shed some light on each of the three building blocks of the TIS concept. Actors in a TIS could be firms, users, suppliers, venture capitalists or other organisations. In the field of energy, it has been suggested that non-commercial organisations acting as proponents of specific energy technologies are relevant significant actors in many technological systems (Unruh, 2000). Jacobsson and Bergek (2004) also thought that particularly important actors in a TIS are the 'system builders', i.e. a notion that originates from the work of Hughes (1979) on the historical development of electric light and power in the USA. In effect, system builders comprise a set of actors who are technically, politically and/or financially powerful enough to strongly influence the development and diffusion processes of a technology. Networks, on the other hand, constitute important channels for the transfer of both tacit and explicit knowledge. They also influence the perception of what is desirable and possible, i.e. they shape the actors' images of the future, which could then guide their specific decisions (Jacobsson and Bergek, 2004). Finally, Edquist and Johnson (1997) explain that institutions stipulate the various constraints (e.g. rules and norms) shaping and regulating interaction between actors, as well as the behaviour and value base of various segments in society. It has been argued, both in the literature related to institutional economics (e.g. Edquist and Johnson, 1997) and to SI (e.g. Carlsson and Stankiewicz, 1991; Lundvall, 1992), that institutions are important, not only for the specific path a technology takes, but also for the growth of new industrial clusters and the rate of technological change. While some SI authors occasionally use the term 'institutions' to mean different things – e.g. to refer to what are normally called organisations (Nelson and Rosenberg, 1993) – they do not represent the mainstream view that coincides with that of Edquist and Johnson.

In essence, the predominant focus of the TIS concept is on the activities of different actor-groups that are horizontally and/or vertically linked for the purpose of generating, diffusing and utilising specific technologies. The SIS concept, on the other hand, is a much broader concept, focusing as it does on competitive relationships among a wide range of actors by explicitly considering the role of the 'selection environment', which is at the core of the processes of innovation, learning and discovery as well as of the process of the diffusion of technical and organisational innovations. The notion of a selection environment was first introduced by Nelson and Winter (1982) to refer to the context, generated by considering relationships between market and non-market organisations and institutions, in which variations of designs/technological options are judged. Raven (2005) explains that a technological design becomes successful if it is repeatedly selected in the selection environment whilst unsuccessful designs are abandoned, i.e. this is the equivalent of the 'survival of the fittest' in the biological setting. In fact, by emphasising the role of the selection environment and by giving due consideration to the transformation of sectors, the SIS concept has called for a departure from the conventional

field of industrial economics. The academic field of industrial economics has mainly been concerned with analysing industrial structure and competition in a stable world, and does not speak of innovation. Rather, it focuses on issues like market competition, the structure of markets, labour costs, etc. (e.g. Bain, 1956; Scherer, 1990; Sutton, 1991; Tirole, 1988). Perhaps this explains why the word 'sector' and not 'industry' was used as part of the SIS concept; i.e. to stress the importance of considering the innovation processes for well-established globalised industries in a dynamic world. Since sectors vary in terms of knowledge accessibility and sources of technological opportunities, the SIS concept – when compared with the TIS concept – places considerable emphasis on the knowledge and technological domains. The SIS was defined, when first introduced by Breschi and Malerba (1997), as being:

> …a system (group) of firms active in developing and making a sector's products and in generating and utilising a sector's technologies; such a system of firms is related in two different ways: through processes of interaction and cooperation in artefact-technology development and through processes of competition and selection in innovative and market activities (p. 131).

Another definition was later provided by Malerba (2002):

> …a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products (p. 250).

More recently, Malerba (2005) has broken down the main structural elements of an SIS into: knowledge and technologies, actors (i.e. firms and other organisations) and networks, as well as institutions (e.g. standards, laws and regulations). Thus, in order to understand the dynamics and the innovation processes of a given sector, one needs to give due consideration to these five key elements. According to SIS thinking, successful new technologies emerge from a favourable combination of all of these factors. It is concluded that, by focusing on these key characteristics of a sector, one might be able to unfold the 'dominant design', 'paradigm' and the 'trajectory' of that sector. Therefore, by stressing the role played by sector and technology-specific factors, it could be argued that SIS has some links to the notions of technological trajectories and paradigms (De Liso and Metcalfe, 1996; Dosi, 1982). To sum up, Figure 2 shows some of the key intellectual traditions and theoretical concepts which are related to the concept of SIS, along with its main five elements:

Figure 2: Theoretical Bases and Main Building Blocks of the SIS Concept

Clearly, SIS xis an exceptionally theoretically rich and fascinating concept because it presents a rather well-articulated, multi-dimensional, integrated, dynamic and systemic view of innovation in globalised sectors; as such, it could provide a framework for the understanding and analysis of a sector, as well as allowing comparative analysis across a range of sectors (Malerba, 2005). It is a framework that should help in analysing complex dynamics, because it takes into account multiple actors, policy-makers and institutions at different levels. Indeed, the relationships and interactions between research, innovation, institutions, actors and competitiveness are neither clear nor straightforward. SIS is also interesting because – at least in theory – it announces a departure from industrial economics, which traditionally has focused mainly on analysing structures and studying competition in a stable world. The SIS concept, on the other hand, is based on the construction and transformation of a dynamic world. So SIS communicates dynamics and sees actors as part of the interaction. It also corresponds to the network model of innovation, and the issues of specialisation and the globalisation of industries and markets. Last but not least, not only is SIS different from industrial economics, which has not on the whole been concerned with innovation, it is also much broader than the TIS concept.

CONCERNS ASSOCIATED WITH USING THE CONCEPT OF SIS

There seem to be certain shortcomings and concerns associated with the SIS concept. To begin with, there are issues which are common to all approaches to innovation systems. For instance – as indicated earlier – there seems to be no consensus on what the term 'institution' means. In addition, there are still ambiguities regarding how a system's boundaries are defined. Since the concepts related to innovation systems are still fairly loosely defined, they should at best be regarded as flexible and adaptable analytical frameworks but not as theories (Carlsson et al., 2002b; Edquist, 1997). When looking specifically at the case of SIS, despite its attractiveness, there seem to be a number of additional concerns. In spite of the SIS claim for the need to consider a range of actors, there seems to be a persistent perception among initial SIS proponents that private firms, their capabilities and learning processes are the major drivers of innovation. It could, however, be argued that when one looks into a system, there has to be a holistic view of all relevant actors (sectoral and otherwise) because it would not be feasible to understand the trajectory of one actor without understanding that of others. The main empirical applications of the concept of SIS are contained in a book edited by Malerba (2004), which analysed six major European sectors. Unfortunately however, whilst the book provides an excellent data source for those interested in the sectors analysed, the analysis largely follows in the footsteps of historians and industrial economists in their study of the industries concerned. For instance, it could be demonstrated that globalisation is not necessarily simply about the globalisation of markets but is also about the internationalisation of markets and their infrastructures (e.g. institutions, including regulations). That is an essential feature that has not received adequate attention in the analysis. Not only has there not been a substantial emphasis on knowledge domains, but the analysis of the rather highly-regulated pharmaceutical sector, for example, has somewhat overlooked the potential key role of institutions in the innovation process. Geels (2004a) further notes that the application of the SIS concept has so far concentrated on the de-

velopment of knowledge, and overlooked the diffusion and use of technologies. Thus, whilst the SIS seems an interesting and appealing concept for studying sectoral transformations, the way it is operationalised remains open to question. One obvious reason is that the SIS concept is still a comparatively recent academic framework, in that the first publications relating to it appeared around 1997 (i.e. Breschi and Malerba, 1997; Edquist, 1997). Moreover, the SIS concept seems particularly concerned – at least thus far – with examining the innovation processes for developed and already-established global industries (or sectors), which are not really the remit of this paper. Apparently, the SIS concept has, until now, failed adequately to explain how new sectoral systems emerge, and how a link is established with the existing sectoral systems (Malerba, 2002, 2006). Whilst such questions form a legitimate basis for an interesting research investigation, some concerns which may potentially restrict the basing of this current research on the concept of SIS need to be acknowledged.

One could argue that the specifics of energy technologies matter to a certain degree, especially when it comes to developing governmental and/or public support. There could be important technology-specific forces at play which are not captured by an analysis of the overall renewable energy industry. Therefore, in order to truly understand the mechanisms driving or blocking particular energy technologies and industries, one perhaps needs to look at specific technologies (Borup et al., 2007). Focusing on the commonalities of all renewables in a country may indeed be meaningful, possibly as a first step (cf., e.g. Johnson and Jacobsson, 2001). However, it is important to consider what these commonalities are. The definition of a sector in the SIS concept has so far been based largely on inputs, in terms of knowledge and the technological base (Malerba, 2004). As has been suggested by Miozzo and Walsh (2006), an SIS is usually characterised by its basic technologies and its knowledge base. This is mainly because the axis of contention concerns the sourcing of knowledge-related inputs to the production process. One could argue that the renewable energy sector (and the overall energy sector in general) is, however, defined usually through its common output (i.e. energy). "There are also some common inputs in terms of knowledge and technology, but this is not necessarily the most important reason for treating renewable energy technologies as a single system. Instead, what tend to hold the renewable energy sector together are mainly a common output and a demand market, as well as the 'glue' provided by an institutional framework that – to a considerable extent – overlaps several energy technologies" (Bergek, 2007). One could therefore suggest that it might be problematic to apply the SIS concept to the energy sector. Perhaps this would explain why almost none of the previous studies on the drivers and barriers affecting the development of renewable energy industries have been based on the recently introduced SIS concept. Instead, studies like those of Bergek (2002) and Jacobsson et al. (2004) concluded that the specifics of technologies matter. For this reason they were based on the concept of TIS, which is a more developed academic concept than the more recent SIS.

ARTICULATING AN INTEGRATIVE SIS-NIS FRAMEWORK

The original purpose of the NIS concept was to analyse the source of competitiveness of nations. Whilst the NIS fails to consider industrial factors in its conceptual frame-

work, the SIS concept allows for the mapping of actors and innovation capabilities at the industry level. However, since SIS does not include national differences in its building blocks, it cannot explain such things as how and/or why certain pioneering firms within a particular industry usually come from certain countries. In this regard, it is believed that the flexible nature, if not vagueness, of the definition of an SI allows researchers to focus on what they think is critical. In essence, the term 'system' in the SI perspective is a theoretical construct that could be applied and defined loosely according to the research context. For studying the emergence of renewable energy industries in particular countries, it is proposed to consider the SIS-NIS interface, with a particular emphasis upon the SIS component (which naturally relates to the innovation patterns at industry level, yet does not consider national differences). It is true that the more globalised an industry becomes, the more likely it is to have a sectoral system at the world level (and the less dependent it is on the national framework). The SIS also seems to be more relevant to industries which have a standardised institutional (or regulatory) framework, such as pharmaceuticals. Nonetheless, for industries that are linked to utilities (e.g. the power and water sectors) or those that have changing regulatory dimensions across different countries, it is important to consider the role which both sectoral and national innovation dynamics play.

Speaking about the potential overlaps between SI concepts, Carlsson and Stankiewicz (1991) affirm that "…where the boundaries are drawn depends on the circumstances" and the scope of the study (p. 111). Moreover, whilst it is proposed to focus the analysis at the intersection level between SIS and NIS, there has to be an awareness of the relevant international connections. According to Malerba (2006), there is a need for an empirical explanation of the factors that affect the innovative performance of countries from an SIS perspective. Strictly speaking, it would be interesting to investigate the relationships between actors, networks and the national institutional framework that determine the international performance of sectors in specific countries. Whilst it might be justifiable to regard a renewable energy industry as a cluster of several technological systems, and not necessarily a sectoral system as defined per se in SIS terminology, two additional reasons could be advanced to justify the attractiveness of basing the analytical framework mainly on the SIS, and not the TIS, concept.

Firstly, for countries that do not currently have a fully-fledged renewable energy industry, it might be beneficial to look – in general as a first step – at the sector level. In further research, one could then perhaps look in more detail at technology-specific innovation processes and the diffusion prospects of the renewable energy technologies under consideration. The application of only the technology-orientated TIS approach – which tends to focus on the micro level – carries the risk of overlooking the more general patterns at the macro level, such as knowledge development and innovation opportunities (Borup et al., 2007). In other words, this present paper argues that there might be a need to go beyond the narrow scope of the TIS concept and to think about how a product, which is produced through multiple and different technologies and bodies of knowledge, ends up defining a sustainable energy system. Instead of treating renewable energy industries as clusters of technologies, one may regard these low-carbon energy technologies as subsystems within the renewable energy sector.

It is true that each established sub-technological system in a 'well-developed' renewable energy sector could be characterised by specific characteristics of the knowledge base, specific actors, institutional linkages with markets and demand that keep things together. Nonetheless, this should not imply overlooking the apparent crossover of boundaries, actors and institutions across all sub-technological systems, especially when examining the case of 'emerging' renewable energy sectors.

Secondly, to the best of the author's knowledge, the renewable energy sector has not yet been studied from the perspective of SIS. Consequently, there might be an opportunity to present new insights with regard to the innovation literature and hopefully to make some useful contribution to the existing body of theoretical knowledge. In spite of the above-mentioned SIS emphasis on the common inputs in terms of knowledge and technology, it could be argued that applying SIS to the energy sector (which, incidentally, is a highly important sector that drives a range of other industries and innovation activities) is relevant when bearing in mind that there is no more truly dynamic and/or global market than energy. Oil, for instance, is a fluid commodity easily shipped between producers and consumers all over the world and around the clock. Every little variation in supply or demand can send ripples around the world, causing spikes in the oil price. An exception to the statement that there have been no empirical applications of the SIS in the energy industry, might be a study by Balaguer and Marinova (2006), which was re-published again in Marinova and Balaguer (2009). This study adopted a broad historical-evolutionary perspective in order to study the historical evolution of the solar PV sector in Australia, Germany and Japan. Another similar study (Kristinsson and Rao, 2006) compared the evolution of the wind turbine industry in Denmark and in India.

Therefore, working on the SIS-NIS interface appears attractive as a means of investigating the potential emergence of national renewable energy industries. By arranging the empirical findings about a country in terms of SIS dimensions, one could also trace ways in which, for example, a particular combination of actors, interactions, knowledge, technologies or specific institutional set-ups might affect the possible emergence of a renewable energy sector in a given country. The SIS framework suggests that successful sectoral dynamics emerge from a favourable combination of these factors. Such a framework could also be beneficial in examining the real barriers (i.e. systemic failures) that may impede a transition towards renewables. Examples of systemic failures, or imperfections, are abundant in the literature (e.g. Johnson and Jacobsson, 2001; Malerba, 1997; Smith, 1999). Having conducted a synthesis of this literature, Woolthuis et al. (2005) developed a 'systemic failures framework', which suggests that systemic failures can be typically grouped into the following broad categories: infrastructural (related to actors and artefacts), institutional (related to institutions), interaction (related to networks) and capabilities (related to actors). It is argued that adopting this relatively simple categorisation, which has the potential to bring order to data concerning systemic failures, can be beneficial in providing some useful leads for innovation policy design.

FUNCTIONS IN INNOVATION SYSTEMS

Concepts related to SI, including that of the SIS, have recently been criticised for their simplistic focus on structural elements,

and tendency to overlook the dynamics of the respective innovation systems. Moreover, it is often mentioned that policy-makers often tend to find it difficult to extract sufficiently practical guidelines from SI studies (Bergek et al., 2008a). Since the interest of this paper lies in creating insights into the dynamics, and policy-orientated factors, that determine the establishment of renewable energy industries, an analysis of the dynamics of the SIS approach adopted is needed. Here, it is worth noting that in a remarkable attempt to go beyond structural components and in order to describe the underlying processes, some TIS-oriented scholars (including Bergek and Jacobsson, 2003; Johnson, 2001; Johnson and Jacobsson, 2001) have focused on the key processes that need to be served for a new innovation system to perform well. These key processes are labelled 'Functions of Innovation Systems' or 'System Functions', and represent the most important factors that arguably could influence the development and widespread diffusion of the technology under consideration. It is argued that a well-functioning TIS is a requirement for the technology under consideration to be developed and widely diffused (Negro and Hekkert, 2008). Since the functions perspective allows for a more systematic approach to mapping determinants of innovation, one could argue that it increases the analytical power of the traditional SI approach. In addition, Bergek et al. (2008a) stated that it provides SI analysts with an innovation 'process focus' that supplements the 'structural focus', which is inherited in the abovementioned categorisation of 'systemic failures' provided by Woolthuis et al. (2005). Hekkert et al. (2007) further believed that the adoption of the functions approach has the potential to deliver a clear set of entrepreneurial-driven policy targets and the instruments to meet these goals, as the performance of the innovation systems could be evaluated in terms of how well the functions (defined here as innovation-related activities or processes) are served in the system. "It is in these processes where policy-makers may need to intervene, not necessarily the set-up of the structural components" (Bergek et al., 2008a: 409).

Apparently, given the enormous recent interest in the system functions approach, a large number of function lists have appeared in the SI literature (e.g. see Bergek et al., 2008a; Liu and White, 2001; Markard and Truffer, 2008). Many of these functions were originally proposed for the TIS concept, but their suitability with regard to understanding the dynamics and functionality of SI at the industry level has also been confirmed by a number of scholars (e.g. Bergek et al., 2005; Johnson and Jacobsson, 2001). The most comprehensive – and empirically tested – set appears to be a system function list that has recently emerged as a result of several empirical studies at Utrecht University in the Netherlands (e.g. Hekkert et al., 2007; Negro, 2007; Negro et al., 2008; Negro and Hekkert, 2008). The following is a brief discussion, based on these studies, of the system functions proposed.

5.1 Function 1 – Entrepreneurial Activities

The role of the entrepreneur is to turn the potential of new knowledge development, networks and environments into concrete actions that generate, realise and take advantage of business opportunities. Entrepreneurs can either be new entrants with visions of business opportunities in new markets, or incumbent companies who diversify their business strategies to take advantage of new developments. The role of entrepreneurs is of prime importance to the

performance of the innovation system, because their often risky experiments are needed to cope with the huge uncertainties that result from evolving combinations of knowledge development, applications and markets. Such uncertainties tend to go far beyond the technological realm, e.g. within R&D laboratories, as they encompass the heterogeneous context where R&D activities may interface with government policies, competitors and markets. Indeed, while SI studies often describe the complex nature of the innovation process in which uncertainty is inherent (Nemet, 2006), not only are knowledge flows across sectors important (Mowery and Rosenberg, 1998), but also lags can be extensive (Rosenberg, 1994). Moreover, since uncertainties are not only limited to early phases in the evolution of an innovation system (Rosenberg, 1996), it is reasonable to propose that the role of entrepreneurs is also essential for later phases. Incidentally, Brannback et al. (2008) indicate that some analysts tend to adopt the triple-helix model of 'government-academia-industry' as a basis for studying SI, while overlooking the critical role of the entrepreneur, in spite of the recurring view in the SI literature that without entrepreneurs no innovation would take place and the innovation system would therefore cease to exist.

5.2 Function 2 – Knowledge Development (Learning)

As indicated earlier, mechanisms of learning are at the heart of the evolution-based SI approach. In this regard, Lundvall (1992) believes that "The most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning" (p. 1). Edquist (1997) further argues that it is important to analyse the knowledge base and learning aspects of innovation systems, including – where possible – systems of formal R&D, patents, education and training, as well as the learning processes that are embedded in routine economic activities.

5.3 Function 3 – Knowledge Diffusion through Networks

Edquist (1997) states that "Not only is the creation of new knowledge crucial but so is its accessibility, i.e. its distribution and its utilisation within systems of innovation" (p. 16). The essential characteristic of networks is to exchange information and diffuse both explicit and tacit knowledge. For instance, when discussing the prospects of establishing renewable energy industries, one could argue the importance of a widespread knowledge of renewable energy technologies as well as an awareness of recent energy and environmental concerns.

5.4 Function 4 – Guidance for the Search

This function "…refers to those activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users" (Hekkert et al., 2007: 423). Borrowing the terminology of evolutionary economics, it could be suggested that if knowledge creation (Function 2) is concerned with the creation of technological 'variety', this function represents the process of 'selection'. Relevant examples exist in the form of some governments setting renewables targets – a review of such targets around the world is provided by RNE21 (2009). Such an action could lead to the enhancement of the credibility of renewable energy, stimulating the allocation of resources and generating momentum for change towards sustainable energy options. Another relative incentive is

the positive belief of the actors with regard to the growth potential of entrepreneurial opportunities in the innovation system. In this regard, Dosi (1982) reported that actors are more likely to search for new knowledge and technologies within their current technological paradigm. If such an observation is true in the case of energy, one would expect the perception of oil producers to be inclined more towards accepting fossil-based clean energy technologies (such as carbon capture and storage technologies) than renewables.

5.5 Function 5 – Market Formation

Since new technologies – sometimes characterised as 'technological discontinuities' – tend to find it difficult to compete with incumbent technologies, it may be necessary to create protected spaces for the new technologies (Winskel, 2006). A review of successful experiences of establishing renewable energy industries indicates that this could be achieved either through (1) the creation of a temporary competitive advantage, e.g. by introducing favourable tax regimes; or (2) the formation of temporary niche markets for specific applications of the technology (e.g. Anderson and Jacobsson, 2000; Berkhout et al., 2004). Within the latter environments, not only can actors, including entrepreneurs, learn about – and exchange – knowledge about the new technology (Functions 2 and 3), but expectations can also be fulfilled and developed (Function 4). In essence, these 'nursing markets' pave the way for opening a 'learning space' in which these technological options can find a place to take shape, before successful 'mass markets' might evolve (Bergek et al., 2008b). Jacobsson and Bergek (2004) went further and argued that since innovations rarely find ready-made markets, these may need to be stimulated or even created, e.g. through the development of positive external economies. Basically, external economies refer to the cost-saving benefits of locating near factors which are external to an actor but internal to a location. Typical sources include locally available skilled labour, or even situations where actors may enjoy 'free utilities' such as 'spill-overs' in terms of knowledge and information flows (Marshall, 1920). Bergek et al. (2008b) further explain that the concept of 'positive externalities' is used in neo-classical economics to refer to outcomes of investments of which the investor cannot fully appreciate the benefits. It is also perhaps of interest here to re-emphasise the fact that energy prices typically do not reflect damage to the environment and to health (i.e. negative externalities). Whilst it is difficult to estimate the size of the negative external economies associated with the use of conventional fossil-based energy technologies, the European Commission indicates 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: 32).

5.6 Function 6 – Resource Mobilisation

A range of different resources need to be mobilised for an innovation system to evolve and develop successfully. Resources in terms of finance and competence (i.e. human capital), as well as complementary assets (e.g. services and network infrastructure) are undoubtedly vital inputs to all activities within the innovation system. When examining the case of renewable energy technologies, the abundant availability of the natural energy 'resource' in question is also an important factor.

5.7 Function 7 – Creation of Legitimacy

It is often argued that, in order for a new technology to develop well, it needs to become part of an incumbent regime. This is of particular significance for technologies which have the potential for disruptiveness, because parties with vested interests may oppose this force of 'creative destruction'. Advocacy coalitions are, therefore, needed both to counteract any change resistance and to facilitate the process of legitimising new technological options and/or trajectories.[1] Sabatier (1988) describes advocacy coalitions as being made up of actors sharing a specific set of beliefs who seek to influence the political agenda in line with those beliefs, in competition with other coalitions. In fact, it has been suggested that such advocacy coalitions can function as a catalyst, as they could put new technologies on the agenda (Function 4), and perhaps lobby for favourable tax regimes (Function 5) and/or additional resources (Function 6). A number of studies (e.g. Jacobsson et al., 2004; Jacobsson and Lauber, 2005) have highlighted the important role played by 'interest groups' in the successful establishment of renewable energy industries. It should be noted, however, that early SI studies used to label this function 'advocacy coalitions' instead of the 'creation of legitimacy'. As pointed out by Bergek (2008a), one might suggest that it is wrong to regard 'advocacy coalitions' as a function, because they are a kind of political network (i.e. a structural component).

Clearly, not all of the above factors, advocated by scholars at the Utrecht University and others, are specific to a single innovation system, since functions may be influenced by factors that affect other systems as well. Moreover, these functions are not independent of each other, as changes in one function may lead to changes in others. In fact, Negro (2007) further suggests that it is the interaction of these functions with each other that leads to "…a build-up of *virtuous cycles* that trigger the development, diffusion and implementation of an emerging technology" (p. 17). Moreover, it is often recommended that all of the above-mentioned functions need to be served for an emerging innovation system to perform well. Nevertheless, borrowing from the underlying assumptions of evolutionary economics, it is imperative to recognise that no theoretical optimum exists. In the words of Markard and Truffer (2008), "There is no optimal structure to assure a well performing [innovation] system" (p. 601). Whilst a consideration of these functions provides some broad indication as to how well an innovation system functions, they should be interpreted as guidelines rather than a 'must-have set' of functions. The simple reason for this is, as conceded by the evolutionary economics theorist Nelson (2007), is that the range of possibilities for any economic activity is constantly changing and growing in a way that cannot be predicted or specified in great detail.

A policy-related explanation was provided half a century ago by Lindblom (1959) when he asserted, in his renowned paper 'The science of muddling through', that: "Making policy is at best a very rough process…Policy-making is a process of successive experimentation on some desired

[1]When examining the case of renewables, the achievement of 'socio-political legitimacy' is likely to be of particular significance. This type of legitimacy could be simply understood as being "...the acceptance by key stakeholders, the general public, key opinion leaders and government officials" (Aldrich, 1999: 230).

objectives in which what is desired itself continues to change under reconsideration" (p. 86). On the basis of that statement, one could presume that the more (and better) functions are served, the better the performance of the innovation system is likely to be, and hence, hopefully, the better the development, diffusion and implementation of innovations will be. This argument is based on the assumption that the fundamental goal of the innovation system is to pursue innovation processes, i.e. to develop, diffuse and utilise innovations (Edquist, 2005; Johnson, 2001). Therefore, this set of functions provides a structure to describe the innovation processes and, contributes to understanding how innovation systems emerge and transform, and also – and perhaps most importantly – how these systems could be stimulated appropriately to successfully support the establishment of emerging SISs. Thus, it is reasonable to suggest – as originally recognised by Negro (2007) – that not only could an empirical analysis of such functions help to pinpoint key mechanisms that induce the diffusion of renewable energy technologies, but insights into these mechanisms could be necessary inputs to derive policy recommendations that may speed up the diffusion process of sustainable energy innovations in a country, i.e. by increasing the strength of inducement mechanisms and reducing the level of various blocking mechanisms. These blocking mechanisms could essentially be regarded as systemic failures which include functional weaknesses as well as structural deficiencies.

In short, it is recommended that the analysis of the prospects for the establishment of national renewable energy industries should to some extent follow the steps broadly outlined in a recent paper (Bergek et al., 2008a), which was merely concerned with analysing functional dynamics of TIS. This paper argues that the first step should involve identifying and examining the structural components of the innovation system under consideration (i.e. the renewable energy sector in a particular country). As previously highlighted, this step requires an examination of five components (actors, networks, knowledge, technologies and institutions) which operate at the SIS-NIS intersection. The second step involves an assessment of the dynamics of the functions, i.e. an examination of how well each of the seven functions is currently fulfilled in the system. This assessment should take into account the sector's phase of development. For instance, it would be wrong to judge the innovation activities of an industry that is supposed to be in a 'formative phase' by using criteria that are more suitable for evaluating an already-established industry that is in a 'growth phase'. The third step entails identifying mechanisms that could either induce (drive) or block (hinder) a development in terms of the desired functional patterns. It will then be possible to specify key challenges facing systematic functionality and to recommend policy interventions that could strengthen/add inducement mechanisms and weaken/remove any blocking mechanisms.

OTHER THEORETICAL PERSPECTIVES

Whilst it is impossible here, because of limitations on space, to provide a detailed account of the nuances of the arguments underpinning other theoretical perspectives, it is perhaps worth briefly highlighting some of these, as a means of at least acknowledging their existence. For instance, it could be argued that relevant, but somewhat limited, academic concepts for studying the development of renewables in energy systems include the notions of 'reverse salient' and

'critical problems', which were articulated by the historian Thomas Hughes in a study of the evolution of large technical systems (LTS). According to Hughes (1983: 79), "[a] reverse salient appears in an expanding system when a component of the system does not march along harmoniously with other components", the cause of which "… may arise from within the system; from its environment, context or from some complex combination thereof" (ibid.: 80). In order to overcome a reverse salient, it is crucial that actors are capable of "…defining reverse salients as a set of critical problems" (ibid.), meaning problems that, if solved, would correct the reverse salient (Christiansen and Buen, 2002). Hughes (1987) also coined the term 'seamless web' in order to indicate the heterogeneous feature of LTS. In the early phases, the web is fragile, requiring system-builders to put in much work to support it. Another related, but somewhat different, theoretical approach is the actor-network theory (ANT), which was proposed by Latour (1987, 1991) and Callon (1991, 1999). One of its proponents, the British sociologist, John Law (1987), affirms that ANT "…borrows much from Hughes's system-building perspective" (p. 113). In an early phase of a new technology, the network consists of only a few elements and linkages. As the network is expanded and more elements are linked together, a technology "…becomes more real." One difference however, highlighted by Summerton (1994), is that researchers using the LTS approach often treat actors "as units *within* the analysis" whilst those using the ANT approach tend to regard actors "as the explicit unit *of* their analysis" (p. 5).

In effect, the socio-technical perspective, in both the LTS and ANT approaches, focuses particularly on linkages in and around emerging technologies, as well as on the activities of different actor-groups. The new configuration becomes more stable as more elements (e.g. technology, user practices, maintenance networks, regulations, etc.) are linked together. The new system gains 'momentum' when more social groups have a vested interest in it. In such a context, energy systems can be characterised as socio-technical systems, and the diffusion of energy technologies is thus a process of creating socio-technical linkages (Kern and Smith, 2008; Shackley and Green, 2007) as opposed to a mere change of techno-economic paradigms (*cf.* Dewick et al., 2006). It has been further suggested that transitions towards sustainable energy systems, which involve long-term change in technical and social/cultural dimensions, take place through the alignment and fruitful interactions between developments on three levels, i.e. (macro-level) landscape, (meso-level) regimes and (micro-level) niches. This latter analytical framework is normally referred to as a multi-level perspective (MLP), and is often associated with the work of Geels (2002a), which has its origins in evolutionary economics, with additional insights from the sociology of technology and the historical analysis of innovation processes.

Borup et al. (2007) and Van Merkerk (2008) assert that there has been a shared understanding between most social studies of technology development (e.g. Bijker and Law, 1992; Bijker et al., 1987; Geels, 2002b, 2004b, 2006) and those of SI studies when it comes to analysing technology dynamics. The two analytical approaches, which both tend to stress the importance of looking at technological change from an evolutionary-based system perspective, have developed in parallel since the mid-1980s and have been in fruitful dialogue with one another. Bearing in mind that every theoretical approach is subject to both praise and criticism, one

of the shortcomings of the MLP approach has been that it places a great deal of emphasis on the niche level. Other challenges are related to governing sustainability transitions as well as geography of transitions, meaning that the role of places and spatial scales in transition processes has not been an explicit concern of the MLP approach (Smith et al., 2010). Moreover, the work of Genus and Coles (2008) and Markard and Truffer (2008) provides a comprehensive critique of Geels' above-mentioned framework. Nonetheless, while there may be many academic frameworks that might be as legitimate as the SI approach, the modified SIS framework that has been adopted appears to be a suitable one for addressing the research topic under consideration. Besides the sociology of choice, SIS is a potentially useful concept that is needed for further empirical application in new sectors and particularly in emerging ones. After all, researchers, especially those with non-positivist leanings, may and should use theoretical frameworks if they find them useful in understanding and interpreting data, without necessarily regarding them as 'general laws' or as reflecting underlying structures.

CONCLUDING REMARKS

Bearing in mind that there has been a dearth of scholarly studies about sustainable energy that have drawn upon conceptual frameworks related to innovation studies, an SI-based theoretical framework has been articulated in this paper. More specifically, this paper argues that the adoption of the modified version of the SIS concept that both (i) borrows the geographical 'national' dimension of the NIS framework; and (ii) is supplemented by an examination of the systematic functionality (an approach originally developed for the TIS concept) could be beneficial for investigating the possibility of establishing future renewable energy industries in given countries. Nonetheless, one cannot overemphasise the futility of the search for a 'magic theory recipe' that guarantees understanding the complex processes behind the establishment of a given national renewable energy industry. In other words, the theoretical framework suggested in this paper, despite its attractiveness, should not underplay the utility of other models – currently dominating the innovation studies field – that could also be helpful in terms of creating new insight into transition processes towards sustainability. One of these models is the MLP, which represents a rather more developed and mature perspective than the SI approach. For instance, it could be argued that emergence or even transitions of SISs can sometimes be driven in response to factors exogenous to the SIS-NIS framework (e.g. some of the 'landscape' processes in the multi-level perspective, such as increased environmental awareness, shifts in ideology, economic crises, etc.). Bearing in mind that SI and MLP are fairly similar in terms of basic concepts and theoretical background, a recent paper by Markard and Truffer (2008) suggests an integrated framework that combines the strengths of the two approaches. Whilst this presents an interesting conceptual direction for future studies on transformation and emergence of innovation, it could be argued that there will always be other useful analytical supplements.

For instance, one could argue that the idea of 'creative destruction' being damaging to incumbents (who could be on the 'losing' side) is a central argument within the SI-based analytical framework adopted in this paper. It appears, however, that one important element when considering the prospects of renewables in many countries lies in the analysis and understanding of the struggle

between new entrants and incumbents, which may consist of powerful political-economic elites. In this regard, it is noted that the functions-based SI perspective adopted does not seem to give due consideration, as part of its analysis, to political-economic aspects related to resistance on the part of incumbents. In this regard, the literature of industrial policy in development economics (infant industries in developing countries) could provide additional interesting insights and potentially a useful analytical supplement. One of the most comprehensive contributions in this scholarly field is a recent book entitled *Industrial Policy and Development: The Political Economy of Capabilities Accumulation* (Cimoli et al., 2009). This book argues that the process of knowledge accumulation and technological development in any high-tech field needs to be matched by a national political economy that is friendly to technological and organisational learning. Hence, rather than believing in the principle of 'getting the incentives right and everything will follow', learning how to seize technological opportunities should be a fundamental driver for catching up. It is true that mechanisms of learning are at the heart of the evolutionary-based SI approach adopted in this paper, but it could be argued that an appreciation of the political economy settlements (such as the organisation and structure of political power in society), which seem to be somewhat overlooked in the mainstream SI perspective, could provide an interesting additional insight into the story of renewables in a given country. Moreover, it could be suggested that discourse should be an important and highly relevant element in any academic endeavour embarked upon for the study of the future prospects of establishing a renewable energy industry within a country. In effect, a political science-based assessment could be made with regard to the potential influence of a range of coalitions supporting different energy discourses, as well as to the prospects for the co-evolution of supporting policy institutions and renewable energy discourse coalitions in the country.

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REFERENCES

Acs, Z., de la Mothe, J., Paquet, G., 1996. Local systems of innovation: towards an enabling strategy, in: Howitt, P. (Ed.), The Implications of Knowledge-based Growth for Microeconomic Policies. University of Calgary Press, Calgary.

Bain, J., 1956. Barriers to New Competition. Harvard University Press, Cambridge.

Balaguer, A., Marinova, D., 2006. Sectoral transformation in photovoltaic industry in Australia, Germany and Japan: contrasting the co-evolution of actors, knowledge, institutions and markets. Prometheus 24(3), 323–339.

Bergek, A., 2002. Shaping and exploiting technological opportunities: the case of renewable energy technology in Sweden. Unpublished Ph.D. thesis: Chalmers University of Technology.

Bergek, A. 2007. On the sectoral innovation system concept. E-mail to Al-Saleh, Y.M. (alsaleh.yasser@gmail.com).

Bergek, A., Jacobsson, S., 2003. The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries, in: Metcalfe, S., Canter, U. (Eds.), Change, Transformation and Development: Schumpeterian Perspectives. Springer, Heidelberg.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmarki, S., Rickne, A., 2005. Analysing the dynamics and functionality of sectoral innovation systems – a manual, the DRUID 10th Anniversary Summer Conference, Copenhagen, 27-29 June 2005.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmarki, S., Rickne, A., 2008a. Analysing the functional dynamics of technological innovation systems. Research Policy 37(3), 407-429.

Bergek, A., Hekkert, M., Jacobsson, S., 2008b. Functions in innovation systems: a framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers, in: Foxon, T., Kohler, J., Oughton, C. (Eds.), Innovations for A Low Carbon Economy: Economic, Institutional and Management Approaches. Edward Elgar, Cheltenham.

Bijker, W.E. Hughes, T.P., Pinch, T.J., 1987. The Social Construction of Technological Systems. MIT Press, Cambridge.

Bijker, W.E., Law, J., 1992. Shaping Technology/building Society: Studies in Sociotechnical Change. MIT Press, Cambridge.

Boekema, F.K. Morgan, K. Bakkers, S., Rutten, R., 2000. Knowledge, Innovation and Economic Growth: the Theory and Practice of Learning Regions. Edward Elgar Publishing, Cheltenham.

Borup, M., Gregersen, B., Madsen, A.N., 2007. Development dynamics and conditions for new energy technology seen in an innovation system perspective, DRUID Summer Conference, Aalborg, 18-20 June 2007.

Braczyk, H., Cooke, P., Heidenreich, M., 1998. Regional Innovation Systems: the Role Governances in a Globalized World. University College of London Press, London.

Brannback, M., Carsrud, A., Krueger, N., Elfving, J., 2008. Challenging the triple helix model of regional innovation systems: a venture-centric model. International Journal of Technoentrepreneurship 1(3), 257-277.

Breschi, S., Malerba, F., 1997. Sectoral Systems of Innovation. In Systems of Innovation: Technologies, Institutions and Organizations. Edquist, C. (Ed.). Pinter, London.

Breschi, S., Malerba, F., 2005. Clusters, networks and innovation: research results and new directions, in: Breschi, S., Malerba, F. (Eds.), Clusters, Networks and Innovation. Oxford University Press, Oxford.

Breschi, S., Malerba, F., Orsenigo, L., 2000. Technological regimes and Schumpeterian patterns of innovation. The Economic Journal 110(463), 388-410.

Callon, M., 1991, Techno-economic networks and irreversibility, in: Law, J. (Ed.), A Sociology of Monsters: Essays on Power, Technology and Domination. Routledge, London.

Callon, M., 1999. Actor-network theory: the market test, in: Law, J., Hassard, J. (Eds.), Actor Network Theory and After. Blackwell: Oxford.

Carlsson, B., Eliasson, G., 2003. Industrial dynamics and endogenous growth. Industry and Innovation 10(4), 435-455.

Carlsson, B., Holmen, M., Jacobsson, S., Rickne, A., Stankiewicz, R., 2002a. The analytical approach and methodology, in: Carlsson, B. (Ed.), Technological Systems in the Bioindustries: an International Study. Kluwer Press: Boston.

Carlsson, B., Jacobsson, S., Holmèn, M., Rickne, A., 2002b. Innovation systems: analytical and methodological issues. Research Policy 31(2), 233-245.

Carlsson, B., Stankiewicz, R., 1991. On the nature, function, and composition of technological systems. Journal of Evolutionary Economics 1(2), 93-118.

Carlsson, B., Stankiewicz, R., 1995. On the nature, function, and composition of technolog-

ical systems, in: Carlsson, B. (Ed.), Technological Systems and Economic Performance: the Case of Factory Automation. Kluwer Academic Publishers, Dordrecht.

Christiansen, A.C., Buen, J., 2002. Managing environmental innovation in the energy sector: the case of photovoltaic and wave power development in Norway. International Journal of Innovation Management 6(3), 233-256.

Cimoli, M., Dosi, G., Stiglitz, J.E., 2009. Industrial Policy and Development: the Political Economy of Capabilities Accumulation. Oxford University Press, Oxford.

Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly 35(1), 128-152.

Cooke, P., Urange, M.G., Extebarria, G., 1997. Regional innovation systems: institutional and organisational dimensions. Research Policy 26(4), 475-491.

Dahmén, E., 1971. Entrepreneurial Activity and the Development of Swedish Industry, 1919-1939. Richard D. Irwin, Homewood.

Dahmén, E., 1989. Development blocks in industrial economics, in: Carlsson, B. (Ed.), Industrial Dynamics: Technological, Organisational and Structural Changes in Industries and Firms. Kluwer, Boston.

De Liso, N., Metcalfe, S., 1996. On technological systems and technological paradigms: some recent developments in the understanding of technological change, in: Helmstädter, E., Perlman, M. (Eds.), Behavioral Norms, Technological Progress and Economic Dynamics: Studies in Schumpeterian Economics. University of Michigan Press, Ann Arbor.

Dewick, P., Green, K., Fleetwood, T., Miozzo, M., 2006. Modelling creative destruction: technological diffusion and industrial structure change to 2050. Technological Forecasting and Social Change 73(9), 1084-1106.

Dosi, G., 1982. Technological paradigms and technological trajectories. Research Policy 11(3), 147-162.

Dosi, G., Nelson, R.R., 1994. An introduction to evolutionary theories in economics. Journal of Evolutionary Economics 4(3), 153-172.

Duysters, G., 1995. The evolution of complex industrial systems: the dynamics of major IT sectors. Unpublished Ph.D. thesis: University of Limburg.

Edquist, C., 1997. Systems of Innovation: Technologies, Institutions and Organizations. Pinter, London.

Edquist, C., 2005. Systems of innovation: perspectives and challenges, in: Fagerberg, J., Mowery, D.C., Nelson, R.R. (Eds.), The Oxford Handbook of Innovation. Oxford University Press, Oxford.

Edquist, C., Johnson, B., 1997. Institutions and organisations in systems of innovations, in: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. Printer, London.

Eliasson, G., 1990. The Knowledge Based Information Economy. Almqvist & Wiksell Internat, Stockholm.

Foxon, T.J., 2003. Inducing Innovation for a Low-carbon Future: Drivers, Barriers and Policies. The Carbon Trust, London.

Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy 33(6), 2123-2137.

Foxon, T.J., Pearson, P., 2008. Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. Journal of Cleaner Production 16(1), 148-161.

Freeman, C., 1987. Technology Policy and Economic Performance: Lessons from Japan. Pinter, London.

Geels, F.W., 2002a. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study. Research Policy 31(8-9), 1257-1274.

Geels, F.W., 2002b. Understanding the dynamics

of technological transitions: a coevolutionary and sociotechnical analysis. Unpublished Ph.D. thesis: Twente University.

Geels, F.W., 2004a. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Research Policy 33(6-7), 897-920.

Geels, F.W., 2004b. Understanding system innovations: a critical literature review and a conceptual synthesis, in: Elzen, B., Geels, F.W., Green, K. (Eds.), System Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Edward Elgar, Cheltenham.

Geels, F.W., 2006. Multi-level perspective on system innovation: relevance for industrial transformation, in: Olsthom, X., Weiczorek, A.J. (Eds.), Understanding Industrial Transformation. Springer, Dordrecht.

Genus, A., Coles, A-M., 2008. Rethinking the multi-level perspective of technological transitions. Research Policy 37(9), 1436-1445.

Hekkert, M.P., Suurs, R., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technological Forecasting and Social Change 74(4), 413-432.

Hodgson, G., 1993. Economics and Evolution: Putting Life back into Economics. Polity Press, Cambridge.

Hughes, T.P., 1979. The electrification of America: the system builders. Technology and Culture 20(1), 124-161.

Hughes, T.P., 1983. Networks of Power: Electrification in Western Society, 1980-1930. The Johns Hopkins University Press, Baltimore.

Hughes, T.P., 1987. The evolution of large technological systems, in: Bijker, W.E. Hughes, T.P., Pinch, T.J. (Eds.), The Social Construction of Technological Systems. MIT Press, Cambridge.

Jacobsson, S., Bergek, A., 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology, Human Dimensions of Global Environmental Change, Berlin, 5-6 December 2004.

Jacobsson, S., Lauber, V., 2005. Germany: from a modest feed-in law to a framework for transition, in: Lauber, V. (Ed.), Switching to Renewable Power: a Framework for the 21st Century. Earthscan Publications Ltd, London.

Jacobsson, S. Sandén, B.A., Bångens, L., 2004. Transforming the energy system: the evolution of the German technological systems for solar cells. Technology Analysis and Strategic Management 16(1), 3-30.

Johnson, A., 2001, Functions in innovation system approaches, Nelson and Winter Conference, Aalborg, 12-15 June 2001.

Johnson, A., Jacobsson, S., 2001. Inducement and blocking mechanisms in the development of a new industry: the case of renewable energy technology in Sweden, in: Coombs, R., Green, K., Walsh, V., Richards, A. (Eds.), Technology and the Market: Demand, Users and Innovation. Edward Elgar, Cheltenham.

Jorna, R.J., 2006. Sustainable Innovation: the Organisational, Human and Knowledge Dimension. Greenleaf Publishing, Sheffield.

Kern, F., Smith, A., 2008. Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. Energy Policy 36(1), 4093-4103.

Klepper, S., 1996. Entry, exit, growth and innovation over the product life cycle. American Economic Review 86(3), 562-583.

Kristinsson, K., Rao, R. 2006. Learning to grow: a comparative analysis of the wind turbine industry in Denmark and India, DRUID-DIME Academy Winter Conference, Aalborg, 26-28 January 2006.

Latour, B., 1987. Science in Action. Harvard University Press, Cambridge, MA.

Latour, B., 1991. Society is technology made durable, in: Law, J. (Ed.), A Sociology of Monsters: Essays on Power, Technology and Domination. Routledge, London.

Law, J., 1987. Technology and heterogeneous en-

gineering: the case of Portuguese expansion, in: Bijker, W.E. Hughes, T.P., Pinch, T.J. (Eds.), The Social Construction of Technological Systems. MIT Press, Cambridge.

Liu, X., White, S., 2001. Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30(7), 1091-1114.

Lundvall, B-A., 1992. National Innovation Systems: Towards a Theory of Innovation and Interactive Learning. Pinter, London.

Malerba, F., 1997. Public policy and industrial dynamics: an evolutionary perspective, in: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. Pinter, London.

Malerba, F., 2002. Sectoral systems of innovation and production. Research Policy 31(2), 247-264.

Malerba, F., 2004. Sectoral Systems of Innovation: Concepts, Issues and Analysis of Six Major Sectors in Europe. Cambridge University Press, Cambridge.

Malerba, F., 2005. Sectoral Systems of Innovation, in: Fagerberg, J., Mowery, D.C., Nelson, R.R. (Eds.), The Oxford Handbook of Innovation. Oxford University Press, Oxford.

Malerba, F., 2006. Innovation in sectoral systems: what we know…and what we would like to know, SPRU 40th Anniversary Conference, Brighton, 10 September 2006.

Malerba, F., Orsenigo, L., 1996. Schumpeterian patterns of innovation. Cambridge Journal of Innovation 19(1), 47-65.

Marinova, D., Balaguer, A., 2009. Transformation in the photovoltaic industry in Australia, Germany and Japan: comparison of actors, knowledge, institutions and markets. Renewable Energy 34(2), 461-464.

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework. Research Policy 37(4), 596-615.

Marsili, O., 2001. The Anatomy and Evolution of Industries: Technological Change and Industrial Dynamics. Edward Elgar, Cheltenham.

Metcalfe, S., 1995. The economic foundations of technology policy equilibrium and evolutionary perspective, in: Stoneman, P. (Ed.), Handbook of the Economics of Innovation and Technological Change. Blackwell, Oxford.

Metcalfe, S., 1998. Evolutionary Economics and Creative Destruction. Routledge, London.

Miozzo, M., Walsh, V., 2006. International Competitiveness and Technological Change. Oxford University press, Oxford.

Mowery, D.C., Rosenberg, N., 1998. Paths of Innovation: Technological Change in 20th-Century America. Cambridge University Press, Cambridge.

Mytelka, L.K., 2000. Local systems of innovation in a globalised world economy. Industry and Innovation 7(1), 15-32.

Negro, S., 2007. Dynamics of technological innovation systems: the case of biomass energy. Unpublished Ph.D. thesis: Utrecht University.

Negro, S., Hekkert, M.P., 2008. Explaining the success of emerging technologies by innovation system functioning: the case of biomass digestion in Germany. Technology Analysis and Strategic Management 20(4), 465-482.

Negro, S., Hekkert, M.P., Smits, R.E.H.M., 2008. Stimulating renewable energy technologies by innovation policy. Science and Public Policy 35(6) 403-416.

Nelson, R.R., 1993. National Innovation Systems: a Comparative Analysis. Oxford University Press, Oxford.

Nelson, R.R., Rosenberg, N. 1993. Technical innovation and national Systems, in: Nelson, R.R. (Ed.), National Innovation Systems: A Comparative Analysis. Oxford University Press, Oxford.

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

Nemet, G.F., 2006. Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy 34(17), 3218-3232.

OECD, 1997. National Innovation Systems. OCED Publications, Paris.

OECD, 1999. Managing National Innovation Systems. OECD Publications, Paris.

OECD, 2005. The Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. 3rd edition. OECD Publications, Paris.

Pavitt, K., 1984. Sectoral patterns of technical change: towards a taxonomy and a theory. Research Policy 13(6), 343-373.

Pavitt, K., 1994. Key characteristics of large innovation firms, in: Dodgson, M., Rothwell, R. (Eds.), The Handbook of Industrial Innovation. Edward Elgar, Aldershot.

Patel, P. Pavitt, K., 1994. The Nature and Economic Importance of National Innovation Systems, STI Review, no. 14. OECD Publications, Paris.

Raven, R., 2005. Strategic niche management for biomass. Unpublished Ph.D. thesis: Eindhoven University.

Robertson, P., Smith, K., Tunzelmann, N., 2008. Innovation in low- and medium-technology industries. Research Policy 38(3), 441-446.

Rosenberg, N., 1994. Exploring the Black box: Technology, Economics and History. Cambridge University Press, Cambridge.

Rosenberg, N., 1996. Uncertainty and technological change, in: Landau, R., Taylor, T., Wright, G. (Eds.), The Mosaic of Economic Growth. Stanford University Press, Stanford.

Saviotti, P.P., Metcalfe, S., 1991. Evolutionary Theories of Economic and Technological Change: Present State and Future Prospects. Harwood Academic Publishers, Reading.

Scherer, F.M., 1990. Industrial Market Structure and Economic Performance. Houghton Mifflin, Boston.

Shackley, S., Green, K., 2007. A conceptual framework for exploring transitions to decarbonised energy systems in the United Kingdom. Energy 32(3), 221-236.

Smith, K., 1999. Innovation as a systemic phenomenon: rethinking the role of policy, in: Bryant, K. and Wells, A. (Eds.), A New Economic Paradigm: Innovation-based Evolutionary Systems. Australian Department of Industry, Canberra.

Smith, A., Vob, J-A., Grin, J., 2010. Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges. Research Policy 39(4), 435-448.

Soete, L., Miozzo, M., 1989. Trade and Development in Services: a Technological Perspective: Working Paper no. 89-031. MERIT, Maastricht.

Summerton, J., 1994. Changing Large Technical Systems. Westview Press, Boulder.

Sutton, J., 1991. Sunk Costs and Market Structure. MIT Press, London.

Stankiewicz, R., 2000. The concept of 'design space', in: Ziman, J. (Ed.), Technological Innovation as an Evolutionary Process. Cambridge University Press, Cambridge.

Tirole, J., 1988. The Theory of Industrial Organization. MIT Press, London.

Utterback, J., 1994. Mastering the Dynamics of Innovation. Harvard Business School Press, Boston.

Unruh, G.C., 2000. Understanding carbon lock-in. Energy policy 28(12), 817-830.

Van Merkerk, R., 2007. Intervening in emerging nanotechnologies. Unpublished Ph.D. thesis: Utrecht University.

Woolthuis, R.K., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design. Technovation 25(6), 609-619.