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The characteristics and dynamics of the Danish energy innovation system in perspective: a patent-based analysis

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1. Research aim and relevance

Technology has a paradoxical role in the greening of the economy: the technological development has been responsible to increase the environmental impacts dramatically during the industrial revolutions (Georgescu-Roegen, 1971; Commoner et al., 1971), but technological change could also be beneficial if new technologies reduce or neutralize the harmful effects of human economic activities (Freeman, 1984). New technological developments present are influenced by new elements (knowledge, routines, institutions, components) but also share some old ones that supported technologies developed in the past (Dosi, 1982), potentially creating lock-in mechanisms that inhibit radical shifts in the techno-economic paradigms.

This narrative suits well to explain why we perceive strong inertia in the process of greening of the industry, as greener technologies might require radical changes in knowledge, institutions, and demand, calling for a better understanding of the transition process from one paradigm to another (Oltra & Saint-Jean, 2006). One of the biggest challenges for sustainability transitions is to analyze how the dynamics of change unfolds over time and what are its main drivers and obstacles. This task is of special importance for the energy sector, in which the transformations are particularly incremental and new technologies require long periods of gestation and experimentation (Borup et al., 2013). While there is a substantial literature on the characteristics of the energy innovation system as a whole and on the overall effects of policy mechanisms in this system, there is a gap related with in-depth analyzes on the dynamics and patterns of energy-related sustainable innovation (Lee & Lee, 2013). Such gap might be related with the lack of energy innovation indicators that are able to cover long periods of time and contain sufficient information necessary to conduct such in-depth analyzes.

Our paper draws upon these evolutionary and technological innovation systems (TIS) elements to investigate the characteristics and dynamics of the transition process towards greener technologies in the Danish energy innovation system (EIS) in comparison with other Nordic countries, namely Sweden, Norway, and Finland, contributing to the still limited literature on the green innovation dynamics at national levels. Moreover, we aim to analyze the rate and direction of the greening in the energy sector in the Danish context. By comparing the characteristics and dynamics of the EIS across different territorial contexts, we aim to contribute to the understanding of the innovative drivers and barriers which is essential to the improvement of decision makers (Coenen & Díaz López, 2010).

2. Theoretical frameworks and methodological approach

Multiple systemic approaches to innovation have been developed along with evolutionary thinking based on the notion that a range of heterogeneous agents can be grouped according to shared characteristics that affect their innovation activities, patterns of learning, and competence development (Edquist, 1997). National and regional innovation systems are often cited in the literature (e.g. Asheim & Gertler, 2006; Cooke et al., 1997; Freeman, 1988; Lundvall, 1992; Patel & Pavitt, 1997) due to the influence that institutional and market structures within geopolitical borders often exert in innovative activities, encouraging agents operating within such borders to follow specific technological trajectories through, for example, policy enforcement (Patel & Pavitt, 1997) or use of local resources and spillovers by agents (i.e. firms, research organizations, universities) as catalysts in the knowledge creation process (Patel & Vega, 1999). Other relevant boundaries of innovation systems in the literature include sectors (in terms of main products and activities) (Malerba & Nelson, 2011; Malerba, 2002) and technologies (Carlsson & Stankiewicz, 1991).

According to Saint-Jean (2006, p. 63) "(…) environmental innovations are thus said to be part of system innovations. The differentiated development of each sub-system can create bottlenecks that can hinder technological development and diffusion". Under the technology-sustainability narrative, the systemic innovation perspective has expanded and incorporated elements such as the user practices, policy and cultural discourses (Geels, Hekkert, & Jacobsson, 2008). New concepts, such as socio-technical systems (STS) were created (Geels, 2004) and old ones were revisited, such as the concept of technological innovation systems (TIS) that, for instance, expanded the previous definition of technological systems (e.g. Carlsson & Stankiewicz, 1991), incorporating the notion of functions and activities within the system as main analytical focus while considering firms as leading organizational units of innovation, supported by other agents (Bergek et al., 2008; Hekkert et al., 2007).

In the eco-innovation context, the TIS framework has been applied to "emergent technologies that have not yet achieved a break-through" (Coenen & Díaz López, 2010, p. 1154), mapping key activities and functions to understand the dynamics of the system over a certain period of time (Hekkert & Negro, 2009; Negro, Suurs, & Hekkert, 2008; Suurs & Hekkert, 2009). Hekkert et al. (2007) suggest the following set of TIS' functions: Entrepreneurial activities; knowledge development; knowledge diffusion through networks; guidance of search; market formation; resource mobilization; and creation of legitimacy, i.e. counteract resistance to change.

While the market diffusion of green technologies is still very incipient, it is possible to have a dynamic picture of the TIS by using indicators that reflect how the functions change over time, and therefore the trajectory of technological change. Patent analysis reveals information about eco-innovation activities whereas other indicators cannot. So far, most firms make no clear distinction between R&D expenditures on eco-innovation and on "traditional" innovation, and innovation surveys are not able to capture the dynamics over time, since they are usually restricted to one or few years and with limited geographic coverage. The level of disaggregation and time coverage of patent data allows one to analyze the evolution of the green technologies - and the transformation of traditional technologies towards lower environmental-harm standards (Haščič & Migotto, 2015). The rate of growth in patenting in a certain technologic field can be used as proxy of its importance and maturity degree (Blind et al., 2009; Chang, 2012; Haupt et al., 2007; Nesta & Patel, 2005), and patent applications are considered a robust indicator of technological competences (Breschi et al., 2003; Chang, 2012).

The paper uses data from the OECD REGPAT database (Maraut et al., 2008), which links the patent data with regions according to the addresses of the applicants and inventors. The addresses of the applicants will be used to distinguish the patents associated with the Danish EIS. A remarkable challenge in analysis based on patent data is how to establish the link between patents and technological areas such as energy production. Instead of relying on keywords to identify green patents like most existing studies (e.g. Oltra & Saint-Jean, 2009; Rizzi et al., 2014; Sierzchula et al., 2012; Wesseling et al., 2014), we identified the IPC codes related with several energy-related technologies using the recently developed IPC Green Inventory and the OECD's list of Environmentally-sound technologies (EST). These classifications use specialists in different fields to classify IPC codes related with "environmentally-sound" technologies at very high disaggregation level (often 7 to 9 digits).

With the patents classified by country and technology, we aim to construct a dynamic overview of the development of energy-related technologies and how they respond to changes in the system, particularly changes in the policy framework. Accordingly, the paper analyzes the relative growth and concentration of patenting activity in each technologic group, the main actors involved, and the generation of new knowledge (i.e. new patterns of combinations of IPC codes) and put these elements in perspective with major policy changes at national and international levels. To measure the concentration of the patent activity among the firms in the system, we use a Herfindahl-Hirshman index (Herfindahl, 1950; Hirschman, 1964), as suggested by Malerba & Orsenigo (1997).

3. Findings and expected outcomes

This analysis grounded on patent data enhances our understanding of the transition process in both technological and national innovation systems' levels and focus on some of the essential functions of innovation systems, including knowledge development and exchange, the mechanisms affecting the guidance of search, and the mobilization of resources (Hekkert & Negro, 2009; Hekkert et al., 2007). Moreover, the methodology offers opportunities for future comparisons between this and other national cases, adding up to the still incipient literature on national EIS (Borup et al., 2008; Jacobsson & Bergek, 2004; Negro et al., 2007). By observing the existence (or not) of patterns of change in agents' technological strategies (in terms of their patent portfolios), one is able to understand which dimensions stand out as main drivers of innovation (Patel & Pavitt, 1997) and what is the role of main policy events and other institutional changes in influence the development of new technologies in the energy area.

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