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Competing innovation systems and the need for redeployment in sustainability transitions

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A B S T R A C T

According to sustainability transitions theories, innovation policies should create protective spaces ('niches') for promising new technologies. Moreover they should support a cumulative process of market formation and growth. Based on results from comparative case studies of two competing technological innovation systems for heavy transport (biogas and electrification), this paper argues that these recommendations are contradictory when technology alternatives with different degrees of maturity compete for the same niche. Should innovation policies open up the niche for the promising but immature alternative, or should they continue to support the technology that already has attained a niche position? If this contradiction remains unsolved, there is a risk for conflicts that block the progress of both alternatives. The paper suggests that there is a need for differentiated policies to resolve the contraction. In order to facilitate further development of both systems, the paper suggests that niche nurturing for immature systems needs to be combined with redeployment into new market segments for more mature systems.

1. Introduction

The technological innovation system has emerged as an influential concept in academic debates on the design of policies to stimulate environmental innovations and facilitate sustainability transitions (e.g. Binz et al., 2012; Hekkert and Negro, 2009; Markard et al., 2009). Several authors in this literature emphasize the need for technology-specific policies based on the argument that environmental innovations suffer from a double externality problem (Oltra and Saint Jean, 2009). Smith and colleagues suggest that there is a need for protective spaces, i.e. narrow areas of application or market segments ('niches') that can nurture the development and early diffusion of alternative new technologies (Smith et al., 2014; Smith and Raven, 2012). Through a cumulative market formation supported by bridging markets (Andersson and Jacobsson, 2000), the innovation system will then gain power and expand, and the new technology will eventually be able to compete with established technologies on mainstream markets (Suurs and Hekkert, 2009b).

Competition between immature and established technologies has been a prime focus in the literature on technological innovation systems and sustainability transitions. However, recent contributors draw attention to more complex processes of competition involving several sustainability alternatives in the same niche (Alkemade and Suurs, 2012; Bakker et al., 2012; Suurs and Hekkert, 2009a; Wirth and Markard, 2011). Such competition presents policy-makers with more difficult challenges than the 'nurture and bridge'-recommendations emanating from the existing literature.

The transport sector poses a notorious challenge for policies intending to reduce greenhouse gas emissions (Stern, 2007) and a highly relevant area for the analysis of competing technologies. Within land-based transport, emissions from heavy vehicles tend to be a particularly difficult issue because of continuously increasing transport volumes. This paper analyses two competing sustainability technologies within this sector in Sweden, where an intense competition is unfolding between the two alternatives biogas and electrification. The purpose of the paper is to understand the emergence of this competition and its implications, the justifications presented for the technologies, and the policies required to support a positive development of both systems.

The next section elaborates theoretically on niches, technological innovation systems, technology competition and processes of market formation. Thereafter, a method section introduces the cases and the research design, followed by two empirical sections on biogas and electrified heavy vehicles respectively. The subsequent section compares the technological innovation systems and discusses possible policy approaches to deal with the challenge of competition between sustainable technology alternatives. A concluding section summarizes the main findings and implications.

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2. Technological innovation systems and the role of niches

2.1. Niches as protective spaces

The concept of niches has obtained a prominent role in theories on sustainability transitions, describing a way for promising new technologies to escape the R & D laboratory. New technologies are often disfavoured by existing selection environments because infrastructures, organizations, practices and regulations are defined according to established technologies. Therefore, new technologies need protection. Niches are important in this respect, shielding the new technology from premature competition, providing a space for the formation of networks to facilitate interactive learning, empowering the emerging innovation system and nurturing radical innovation (Smith and Raven, 2012; Boon and Bakker, 2016).

Synthesising literature on niches and sustainability transitions, Schot and Geels (2008) describe two kinds of niches: technological niches and market niches. Technological niches refer to demonstration projects where technology suppliers meet potential users and other actors, who may influence the shaping of a demand. These niches are instrumental for the articulation of expectations and visions about the new technology. Moreover, they attract attention to and legitimize the technology, facilitate sociotechnical experiments and help building social relationships (Hoogma, 2002; Caniëls and Romijn, 2008). Literature on sustainability transitions present strategic niche management (SNM) as a guidance for policy, emphasising the need to initiate demonstration projects (Harborne et al., 2007; Kemp et al., 1998; Schot et al., 1994). To qualify as technological niches, such policy-supported demonstration projects will have to involve a variety of stakeholders, thus facilitating alignment between the technology and the society (Rip, 1995).

Market niches constitute a successive step. The concept refers to "niches in which technology design and user demands have been stabilised" (Schot and Geels, 2008:539). Hence, rather than describing a space for experimentation, market niches describe possibilities for new technologies to enter a commercial stage. The concept of a market niche rests on an assumption of markets as being heterogeneous, consisting of different segments that describe different application domains and selection environments (Levinthal, 1998). A new technology stands a better chance if it enters in a segment where the particular selection environment is more benign to the technology. Because these segments tend to be relatively narrow and the sales volume small, it is customary to describe them as niches. Case studies suggest that policy has a central role to stimulate the emergence of market niches for cleaner new transport technologies (Sushandoyo and Magnusson, 2014; van der Vooren and Brouillat, 2015). To be successful in this, the policy has to comprise combinations of different instruments such as extended demonstration programs, procurement requirements and subsidies.

2.2. Technological innovation systems

The technological innovation system (TIS) approach presents an elaborated framework on the prerequisites for a successful diffusion of new technologies. A TIS consists of the actors, networks and institutions associated with the technology. These are structural building blocks of the system (Bergek et al., 2008). On the back of its multi-dimensional character, the TIS approach then suggests a number of processes (often denoted 'functions') which are critical for the system to evolve. This includes processes of experimentation into a variety of applications and production methods, knowledge development and diffusion, legitimation, mobilization of resources, direction of search processes and market formation (Hekkert et al., 2007; Hekkert and Negro, 2009; Bergek et al., 2008; Hillman et al., 2011). The functionality of a TIS can be assessed in terms of the relative strengths and weaknesses of these processes, where strengths and weaknesses can be related to factors either within or outside the system (Hellsmark et al., 2016). A key objective for innovation policy then is to stimulate weak processes/functions and remove obstacles that may hamper them.

Different TIS have reached different stages of maturity. A common way to assess maturity is according to the stage of technology diffusion, which tends to follow an S-curved pattern (Geroski, 2000). Analysing cases of renewable energy technologies, Jacobsson and Bergek (2004) make a distinction between the formative stages and the growth stages of a TIS, arguing that different kinds of policies are required to sustain progress during these two stages. Whereas the formative stages consist of pre-commercial R & D and demonstration, as well as early diffusion on niche markets, the growth stages are characterised by diffusion on larger segments and subsequently on mass markets.

A TIS operates in a multi-dimensional context and its contextual interactions differ in terms of strength and dependency. Bergek et al. (2015) distinguish between four kinds of context dimensions: technological, sectorial, geographical and political. *Technological contexts* refer to other technological innovation systems with which the focal TIS interacts. These can be divided into complementary and competing TIS (Markard and Hoffmann, 2016; Sandén and Hillman, 2011). *Sectorial contexts* refer to structures that provide societies with a certain functions, such as energy, transport or food (Malerba, 2002). These structures facilitate production, distribution and use of different services and products. While sectors have similar structural elements as technological innovation systems, sectors incorporate different technologies and a TIS is often embedded in one or several sectors (Bergek et al., 2015). *Geographical contexts* refer to the place in which the TIS is situated. Analyses of TIS have often had a national delimitation, but system evolution depends on activities and interactions at different geographical levels, ranging from local to global (Coenen et al., 2012). While some system actors have a geographical jurisdiction, such as a local municipal board or city council, others operate globally, such as an international firm. The *political context* is about the argumentation for (and against) the technology. The interests of various actors determine their engagement in and relationship with a TIS, and norms, practices and power relations direct possibilities for future developments. The politics of sustainability transitions refer to ideas and understandings about environmental and societal problems that define the space of acceptable solutions (Meadowcroft, 2011).

2.3. Transitions and technology competition

Literature on sustainability transitions tends to embody a normative orientation, describing ways to substitute established technologies in different applications. TIS and SNM present ways to support such substitution processes through technology-specific policies. Two main arguments justify these policies. Firstly, existing selection environments tend to disfavour new technologies and secondly, environmental innovations will make the society more sustainable and therefore they deserve public support (Oltra and Saint Jean, 2009). These arguments warrant policy interventions that may make it possible to attain increasingly larger market shares at the expense of established technologies.

However, the reality may be more complex than one-to-one substitutions of established technologies with new alternatives. Bakker et al. (2012) found that several alternatives often compete for policy protection, justified by promising expectations in terms of sustainability. The authors conclude that although there could be room for a number of different alternatives in local demonstration projects, a continued development and growth will require some selection. Moreover, Wirth and Markard (2011) have shown that effective support schemes may foster a lock-in to certain technologies. Thus, there is a risk that policy-support will result in a barrier for the development of newer, less mature but more promising alternatives. Farla et al. (2010) argue that in sectors such as energy and transport, which require large infrastructural investments, earlier decisions can result in irreversibility and lock-ins. Therefore, sustainability transitions require higher-level