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Structural dynamics of innovation networks funded by the European Union in the context of systemic innovation of the renewable energy sector

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HIGHLIGHTS

- This study evaluates the systemic innovation performance of networks.
- A time-series analysis of network structural properties was conducted.
- The network shows disconnected local clusters for technology and market innovation.
- The local clusters supporting exploration and exploitation have weakened with time.
- The networks have not evolved into a systemic direction.

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ABSTRACT

Innovation in the renewable energy (RE) sector relies on the concept of systemic innovation, which requires interaction between two innovation aspects: technology exploration and market exploitation. The European Union (EU) has introduced political instruments for systemic RE innovation by integrating resources from different thematic and geographic areas. However, using these instruments to establish an ecosystem for systemic innovation remains unexplored. This study develops a framework for evaluating the systemic innovation performance of networks through a time-series analysis of network structural properties. Overall, EU-funded innovation networks have not evolved in a systemic direction. First, the network exhibits densely connected local clusters for technology exploration and market exploitation of RE innovation, which are disconnected from each other. Over time, the gap between the two phases has weakened with increasing connectivity, but the local clusters supporting either explorative or exploitative activities have diminished. The existing networking linkages among organizations are considered ineffective because their positions in the network tend to display a mismatch with their innovation patterns. This research presents policy suggestions for optimizing the exploration and exploitation activities in the EU's funding program and their complementarities to establish a systemic innovation environment in the RE sector.

1. Introduction

Innovation in renewable energy (RE), hereafter referred to as RE innovation, entails risky investments because of the greater technical uncertainty and lower market sophistication than that in conventional energy fields (Balachandra et al., 2010; Del Rio, 2011; Walsh, 2012). RE innovation is disruptive because it deviates from the traditional market and technology base (Balachandra et al., 2010). The return on investment requires long-term effort because high initial costs and immature market infrastructures often lead to the monitoring of individual and societal benefits of RE innovation on a large scale (Balachandra et al., 2010; Del Rio, 2011).

Systemic innovation has been recently highlighted as a cornerstone for abandoning existing hydrocarbon-based technologies (Klevas et al., 2014; Mallett, 2007; Negro et al., 2012; Shum and Watanabe, 2009). Innovation in complex systems, such as RE

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innovation, is difficult to achieve because such action necessitates revolution in behaviors, structures, and processes that have been optimized around their current formats and interests and combined with specific societal relationships (Doranova et al., 2012). This transformation process can be effectively addressed when the entire innovation cycle from research and development (R&D) is well-connected to the exploitation of the R&D results in the market. Thus, this process can be facilitated by systemic innovation, which relies on interconnections that influence one another in terms of the parts of the system and the manner of their interaction (Chesbrough and Teece, 1996; De Laat, 1999; Teece, 1986, 1996). As such, RE innovation is considered systemic when R&D technology shifts into and emerges from market exploitation, creating a synergistic interaction between the technology and the market.

The network, which is a central means for systemic innovation, has been considered effective on RE innovation, especially at the international level. The international network plays a significant role in the R&D of RE technologies by providing opportunities to combine expertise for creating new technologies over a restricted organization, thematic field, or geographic area (Bosetti et al., 2008; Liu and Liang, 2013; Musiolik et al., 2012; Ru et al., 2012; Zhao et al., 2011; Zhou et al., 2012). Regarding market exploitation, previous modeling efforts have confirmed the cost benefits of collaborative RE utilization, which signifies the transfer of RE technologies to share the output of RE generation (Barker et al., 2009; Charles et al., 2009; EC, 2012, 2013; Fichtner et al., 2001; Gullberg et al., 2014; Jacobsen et al., 2014; Orans et al., 2007). Considering these two perspectives, the international network is predicted to be viable for systemic RE innovation by overcoming difficulties in the transition from R&D to demonstration, which is called the innovation valley of death (Liu and Liang, 2013).

Although the systemic approach for RE innovation is widely practiced in related industries and highlighted by politicians, the extent to which the participating organizations have achieved this coordination and the means of support to their joint efforts by the policies remain poorly understood in academia (Chen and Pang, 2010; Sagar and Van der Zwaan, 2006). According to Poocharoen and Sovacool (2012), only a few studies have elucidated the mechanisms of networks in the environmental and energy fields, e.g., performance variations among different networks and their determinants. At the European level, studies have investigated innovation networks in the general field (Paier and Scherngell, 2008; Roediger-Schluga and Barber, 2006; Scherngell and Barber, 2009) and selected thematic fields, such as information and communication (Breschi et al., 2009; Crespo et al., 2015; Heller-Schuh et al., 2011; Protogerou et al., 2010; Siokas, 2008), health (Ortega and Aguillo, 2010), and space (Balland et al., 2013). Networks in the energy area have been rarely analyzed. The existing literature on collaboration in the RE area tends to address only one aspect of innovation, which is either technological or market innovation, rather than consider the holistic progress. Furthermore, studies on political efforts to improve the systemic performance of RE networks are scarce.

This study aims to examine whether related innovation activities under the European Union (EU)-funded international networks have evolved in a systemic direction and whether EU instruments have contributed to establishing an effective ecosystem for systemic RE innovation. This research initially reviews previous studies on innovation networks, particularly from the European and RE perspectives. Several structural properties of the network are proposed as indicators of a systemic innovation network. Employing network analysis, this research investigates changes in the structural properties of networks formed by organizations participating in the EU innovation programs between 2003 and 2013. In addition, this study explores a case of European organizations to examine whether structural changes in networking are also observed in resource exchange among organizations with different innovation environments.

2. Literature review

Systemic innovation can be viewed as a collective innovation process in the innovation cycle based on the interaction between technology exploration and market exploitation. Studies have highlighted that organizations should employ both explorative and exploitative strategies to achieve long-term success in innovation (Ancona et al., 2001; Benner and Tushman, 2003; Eisenhardt and Martin, 2000; Feinberg and Gupta, 2004; Levinthal and March, 1993; March, 1991). Exploration is described as a shift from existing systems in a continuous search for novel technologies and as abandonment of currently dominant technologies (Ahuja and Lampert, 2001; Henderson and Clark, 1990; March, 1991; Tushman and Rosenkopf, 1992). By contrast, exploitation signifies the implementation, execution, and routinization of existing knowledge and competence sets (March, 1991). Considering these two dimensions, Fig. 1 illustrates four types of innovation activities. Systemic innovation refers to innovation in which the levels of both technology exploration and market exploitation tend to be high such that both activities have limited uncertainties and create synergistic effects.

A network can have a positive effect on systemic innovation because it is viewed as an organizational demography (Owen-Smith and Powell, 2004) encompassing organizations from the entire stages of the innovation value chain from technology exploration to market exploitation (Balland et al., 2013). The role of the network in systemic innovation has been highlighted from the point of view of resource exchange. The acquisition of critical resources through market transactions is difficult to manage and is subject to high failure risks (Pisano, 1990; Teece, 1982). Such market failures motivate organizations to attain technological or non-technological resources through collaborative mechanisms (Hamel, 1991; Kogut, 1988).

In recent decades, the EU has supported collaborative innovation through international networks. The international networks for advancing technical capacity including RE topics have been funded under the Framework Program (FP) since 1984. The international networks for enhancing market competitiveness were supported from 2003 to 2013 under Competitiveness and Innovation Framework Program (CIP), including a sub-program for energy innovation called Intelligent Energy Europe (IEE). Both programs have been integrated under Horizon 2020 since 2014, which is the current and future funding scheme of the EU, to link the whole innovation lifecycle. The EU endeavors to achieve systemic innovation in all thematic areas by simultaneously funding

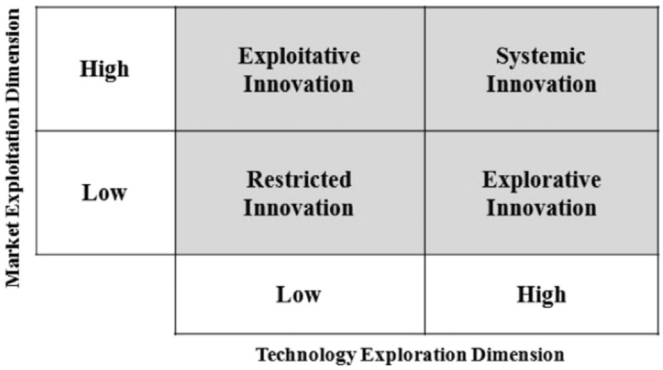

Fig. 1. Dimensions of systemic innovation.