Paper to be presented at

DRUID15, Rome, June 15-17, 2015

(Coorganized with LUISS)

Analysis of the innovation capacities and resource spillovers for systemic innovation of the renewable energy sector in the European Union

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Abstract

Innovation in the renewable energy (RE) sector has built upon the increased complementarities of resources between different thematic areas and geographical region. It, thus, needs to be conducted in a systemic way to address the entire innovation cycle. However, developing successful policies for the systemic innovation in the RE sector requires an in-depth understanding of the innovation environment of the respective country as well as its patterns of sharing the innovation resources with other countries. Therefore, this research aims to establish a conceptual and analytic framework to analyze the existing circumstances for the systemic innovation of the RE sector in the countries of the European Union (EU) and their resource spillovers. By developing indexes, this study, firstly, measures the current status of each country?s absorptive and desorptive capacities with respect to the systemic innovation in the RE sector. In the next step, the inter-influences of the EU countries for the resource exchange in the EU-funded innovation networks are examined. The results show that these interactions are not evenly distributed across the EU but are concentrated around a few countries with superb absorptive capacities in the RE area. In addition, the resource spillovers are rather driven by the superiority of the absorptive capacity, which indicates that the EU policies have been ineffective in supporting the market exploitation and closing the innovation cycle. Finally, the findings suggest implications to complement the limited resources for the systemic innovation in the RE sector within the EU, especially under the Horizon2020 program.

Jelcodes:Q28,D85

Analysis of the systemic innovation environment for the renewable energy sector in the European Union

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Abstract – Innovation in the renewable energy (RE) sector has built upon the increased complementarities of resources between different thematic areas and geographical regions. It, thus, needs to be conducted in a systemic way to address the entire innovation cycle. However, developing successful policies for the systemic innovation in the RE sector requires an in-depth understanding of the innovation environment of the respective country as well as its patterns of sharing the innovation resources with other countries. Therefore, this research aims to establish a conceptual and analytic framework to analyze the existing circumstances for the systemic innovation of the RE sector in the countries of the European Union (EU) and their resource spillovers. By developing indexes, this study, firstly, measures the current status of each country's absorptive and desorptive capacities with respect to the systemic innovation in the RE sector. In the next step, the inter-influences of the EU countries for the resource exchange in the EU-funded innovation networks are examined. The results show that these interactions are not evenly distributed across the EU but are concentrated around a few countries with superb absorptive capacities in the RE area. In addition, the resource spillovers are rather driven by the superiority of the absorptive capacity, which indicates that the EU policies have been ineffective in supporting the market exploitation and closing the

innovation cycle. Finally, the findings suggest implications to complement the limited resources for the systemic innovation in the RE sector within the EU, especially under the Horizon 2020 program.

1. Introduction

Over the last decade, the innovation of the renewable energy (RE) has emerged as a central instrument of the European Union (EU) for coping with the global challenges in the era of climate change. The EU underlined a goal to increase the share of RE sources up to 20% in its energy mix by 2020 among the main targets of the Europe's 10-year growth strategy called Europe 2020. To fulfill the goal jointly, the Renewable Energy Directive 2009/28/EC, which allocates binding national targets to each member state to raise the use of energy sourced by RE technologies in their energy consumption, was implemented by the EU. The EU also envisioned a concept of cooperation mechanisms within the framework of the EU directive 2009/28/EC that allows member states to flexibly and jointly exploit RE sources by using transnational measures, such as statistical transfers, joint projects, and joint support schemes (EC, 2013).

The innovation in the RE area, which is referred to as an RE innovation within this study, is considered complex with disruptive, large-scale, and local-specific features. First, RE innovation is characterized by greater technical uncertainty and lower level of market sophistication than conventional energy fields (Balachandra et al., 2010; Del Rio Gonzalez, 2011) because it is generally based on a cluster of emerging knowledge (Balachandra et al., 2010; Walsh, 2012). Second, the return on investment in RE innovation needs long-standing efforts. The individual and societal benefits of RE innovation are hardly realized by discrete and short-term attempts because of the high initial cost and immature market infrastructure (Balachandra et al., 2010; Del Rio Gonzalez, 2011). Finally, RE innovation can be restricted by natural conditions because the technical choices for the energy process, such as generation, transformation, and transportation systems, are dependent on the availability of RE sources in the respective regions to a great extent (Balachandra et al., 2010).

Considering these features, RE innovation needs to be conducted in a systemic way to deal with multi-dimensional innovation barriers, such as technical, economic, and institutional ones (Klevas et al., 2014; Mallet, 2007; Negro et al., 2012; Shum and Watanabe, 2009). RE innovation often entails a range of technological and non-technological changes in procedural and institutional arrangements. As a result, it requires a holistic thinking of the entire innovation cycle from the research and development (R&D) to the market application of RE technologies and the collective effects of all these activities (Chen and Pang, 2010; Sagar and van der Zwaan, 2006).

Similarly, in the EU, the importance of such systemic RE innovation, which means the systemic innovation in the RE sector, has been supported by means of various political and institutional instruments. First, the EU has operated the Framework Program (FP) for advancing technical capacity and Intelligent Energy Europe (IEE) for enhancing market competitiveness in tandem. Recently, notable progress on systemic innovation has been achieved by the EU under the new Horizon 2020 program, which integrates all existing funding instruments for both R&D and market deployment since 2014. Second, the envisioned concept of cooperation mechanisms under the EU's directive fosters systemic RE innovation in the sense that it supports the integration and exchange of resources and capacities to overcome innovation restrictions in the EU countries, such as access to natural resource, grid connection, exhaustion of places, administrative procedures, and support scheme (Balachandra et al., 2010; EC, 2013; Klevas et al., 2014; Walsh, 2012). Third, the EU also provides a variety of financial instruments to fund projects for systemic innovation in the general field of energy. For example, the European Strategic Energy Technology Plan (SET-Plan) set out a future model for pan-European energy research cooperation based on the effective combination of public resources and creation of flexible private-public partnership with industries (Del Rio Gonzalez, 2011). Such measures contribute to overcoming the limitations of the given innovation environments in the EU countries by enhancing the internal capacities of the individual countries and integrating the internal and external capacities beyond the countries' boundaries.

However, the successful implementation of related policies requires an in-depth understanding of the systemic innovation environment of the respective countries as well as the resource spillovers for combining the technology development and market deployment activities. Nevertheless, the status of innovation conditions or innovation-oriented interactions for the systemic RE innovation has not been fully understood yet. Previous studies, which aimed at analyzing the innovation environment, focused on the commercialization or entrepreneurship aspects and did not address the systemic innovation aspect (Brem and Voigt, 2009; Gans and Stern, 2003; Walsh, 2012). Several studies also examined resource flows between countries in the RE area (Du et al., 2014; Rizzi et al., 2014). Still, they were mostly confined to either technology-side or market-side activities and did not consider the holistic innovation lifecycle.

To fill this gap, this study aims to establish a conceptual and analytic framework to identify the existing capacities and resource exchange activities for the systemic RE innovation in the EU. Toward this goal, a comprehensive review of the literature on RE innovation and systemic innovation is performed to establish theoretical and empirical foundations for this research. This work suggests four distinct innovation environments segmented by two dimensions of technology exploration and market exploitation: ambidextrous, explorative, exploitative, and blocked environments. Relevant data are collected and utilized to develop indexes for each dimension, by means of which the EU countries' capacities for promoting the RE area are evaluated and classified. Each environment affects the strategy options for the systemic RE innovation of the respective countries, particularly in terms of resource acquisition and integration. In this sense, country-level networks formed by the EU-funded projects from 2003 to 2013 are investigated to understand how the countries with different innovation environments have integrated their innovation resources to strengthen the systemic innovation capacities in the RE sector over time. Finally, the implications derived from the analysis are discussed and strategies for the different stakeholders are suggested.

2. Literature review

Recently, a dichotomy of technology-push and market-pull has been applied to analyze driving factors of the RE innovation (Nemet, 2009; Norberg-Bohm, 2000; Taylor, 2008; Walsh, 2012). Innovation literature often underlines two types of innovation impulses, technology-push and market-pull, as the main drivers for diffusing technology into the market. On the one hand, RE innovation can be led by the improvement of technologies and application demand of the R&D results without considering customer needs (Brem and Voigt, 2009; Herstatt and Letti, 2004). On the other hand, it can be pulled by external market forces in response to an identified market need for innovative RE technologies and problems, which cannot be solved with existing technologies (Brem and Voigt, 2009).

In accordance with this dichotomy, many scholars (e.g., Ancona et al., 2001; Benner and Tushman, 2003; Eisenhardt and Martin, 2000; Feinberg and Gupta, 2004; Levinthal and March, 1993; March, 1991) stressed the need for companies to engage in both explorative and exploitative strategies to be successful in the long run. Exploration can be characterized by breaking away from existing dominant technologies and shifting away from existing systems in constant search for novel combinations (March, 1991). In RE innovation, exploration strategy is especially required for inventing and advancing the innovative RE technologies in R&D activities. By contrast, exploitation can be characterized by the implementation, execution, and routinization of the existing knowledge base and competence set (March, 1991). In RE innovation, exploitation strategy is necessary for deploying RE technologies in the market and increasing the use of RE sources. Exploitation can bring about immediate and positive returns but may lead to technological obsolescence in the end (March, 1991). Therefore, exploration and exploitation should build upon each other, that is, exploration should shift into exploitation and exploration should emerge from exploitation. For this reason, both exploration and exploitation strategies need to be pursued in tandem to establish systemic RE innovation.

Considering these innovation dimensions, previous literature elaborated the innovation environment and suggested frameworks and strategic options for innovation under the given circumstances (Brem and Voigt, 2009; Gans and Stern, 2003; Walsh, 2012). Brem and Voigt (2009) introduced the technology-push and market-pull aspects for proposing a theory-based conceptual framework and developing front-end innovation models. Their research suggested implications on how the activities for technology-push and market-pull can be integrated within the corporate technology and innovation management. Gans and Stern (2003) presented four distinct commercialization environments divided by the extents of technology excludability and complementary assets to derive strategic choices available for start-up and established companies. Regarding the RE sector, Walsh (2012) incorporated both the dimensions of market demand and eco-sophistication of the market from a market dynamic perspective and developed a conceptual framework to characterize the four types of commercialization innovations of RE technologies. However, the previous frameworks focused on the commercialization and entrepreneurship objectives rather than the systemic innovation context. As a result, the elements and indicators employed for elaborating the innovation environments involved mixed viewpoints of technology exploration and market exploitation. For example, in the framework by Walsh (2012) focusing on the RE sector, institutional and social factors were viewed as the elements of the technology-push dimension, even though those factors were also closely related to the market-pull dimension.

Over the last decade, the alliance network has been viewed as an important instrument to the increase in the complementarities of resources and capacities for both technology exploration and market exploitation in the RE sector (Aslani et al., 2013; Bosetti et al., 2008; Charles et al., 2009; Foxon et al., 2005; Gullenberg et al., 2014; Jacobsen et al., 2014; Mallet, 2007; Musiolik et al., 2012; Negro et al., 2012; Orans et al., 2007; Ru et al., 2012; Shum and Watanabe, 2009; Zhao et al., 2011; Zhou et al., 2012). Complementing the limited internal resources is of particular importance for succeeding in the disruptive and complex innovation (Bayona et al., 2001; Miotti and Sachwald, 2003), such as the RE innovation (Foxon et al., 2005; Musiolik et al., 2012; Zhou et al., 2012). The technical and organizational interdependencies with the activities performed by external supply chain partners can have significant functions in closing the innovation loop. In this regard, Shum and Watanabe (2009) proposed the systemic concept of innovation value-added chain for promoting RE technologies that involves all the innovation cycle stages including the development and deployment processes of the RE technologies to tackle various innovation hindrances.

The effects of network on systemic RE innovation have been particularly highlighted at the international level (El Fadel et al. 2013; Rizzi et al., 2014). On one hand, the networking effects have gained increasing interests among researchers who addressed the issues on international cooperation for technology R&D, such as joint venture, licensing, and joint design, of the RE technologies (Bosetti et al., 2008; Liu and Liang, 2013; Musiolik et al., 2012; Ru et al., 2012; Zhao et al., 2011; Zhou et al., 2012). In particular, the network for technology exploration was viewed by Ru et al. (2012) as a middle step in the transition pathway between imitative and indigenous innovations and by Liu and Liang (2013) as a strategy to overcome the difficulties arising from the transition from R&D to demonstration, which is called the innovation valley of death. On the other hand, the network for market exploitation is considered effective in collectively carrying out the market deployment activities between countries (Charles et al., 2009; Gullenberg et al., 2014; Jacobsen et al., 2014; Orans et al., 2007). For example, a number of studies and modeling efforts have confirmed the exploitation aspects of the network, such as the benefits from the collaborative RE generation among different countries (Barker et al., 2009; De Jager et al., 2011; EC, 2013; Fichtner et al., 2001). For example, the interaction across EU member states reduces the cost of deploying the RE technologies at 6% lower support cost, 5% lower generation cost, and 3% less capital expenditure (EC, 2013). A study funded by the EU Commission (De Jager et al., 2011) also confirmed that purely national measures for developing RE sources can increase the cost of reaching the EU's 2020 targets by around 2 billion Euros per year.

A question arises as to which capacities are required to combine the R&D resources and improve the collective market potentials of the RE sector through the alliance network. To capture the exploration and exploitation of external knowledge effectively, a different type of capacity is required for each aspect. According to Lichtenthaler and Lichtenthaler (2009), the ability to explore external knowledge is absorptive capacity, whereas the ability to exploit the knowledge externally is desorptive capacity. On one hand, absorptive capacity is required to acquire external knowledge and assimilate this by means of incorporating it into the ex-ante knowledge base (Lane et al., 2006; Zahra and George, 2002). On the other hand, desorptive capacity is required to transfer the internal knowledge to the recipient and make a profit in the market (Lichtenthaler and Lichtenthaler, 2009). Table 1 summarizes the strategies and capacities required for connecting the innovation steps from R&D to market application through the network.

Table 1 Elements for systemic innovation

Objective	Technology development	Market deployment
Strategy	Exploration	Exploitation
Capacity	Absorptive capacity	Desorptive capacity

However, a scarcity of research exists in terms of observing the existing capacities for systemic RE innovation and their exchange patterns among countries, although the successful implementation and improvement of policies require an understanding of the innovation circumstances and performance of the respective countries. Regarding technology exploration, a few researchers attempted to analyze the status of capacities and their flows among countries. For example, Romo-Fernandez et al. (2011) investigated the scientific production of REs of the EU countries. Similar works have been done by Rizzi et al. (2014), who visualized the transition of RE technology competencies and the role of knowledge development by technology topics and countries, and by Du et al. (2014), who carried out a descriptive analysis detecting central countries and organizations in international co-publishing networks in the RE area. With respect to market exploitation, studies have been conducted on the analysis of specific case studies at the organizational or regional levels (Parag et al., 2013; Poocharoen and Sovacool, 2012; Vantoch-Wood and Conner, 2013). Especially, the private-public partnerships between organizations or regions have been addressed with regard to sharing the market capacities and institutional infrastructure for RE-related innovations (Bale et al., 2013; Chaurey et al., 2012; Gullenberg et al., 2014; Martin et al., 2011; Parthan et al., 2010; Peterman et al., 2014; Sovacool, 2013). However, the empirical setting with regard to market exploitation is still weak, being mainly qualitative or focused on restricted cases because of the lack of evidence and measurement methods. In addition, preceding literature tended to focus on one side of the dichotomy, either technology exploration or market exploitation, rather than taking the holistic innovation cycle into consideration. In general, little research has been conducted on how both strategies and respective capacities for the systemic RE innovation are integrated in the EU or worldwide (El Fadel et al. 2013; Rizzi et al., 2014).

Overall, previous studies on RE innovation have highlighted the importance of the systemic approach by analyzing the determinants, dimensions, and strategies of the systemic RE innovation and the capacities required for combining the exploration and exploitation activities in the network. The previous conceptual and analytic frameworks were not sufficient to explain the systemic innovation environments of the EU countries in the RE sector because of their restricted focuses on the commercialization aspect and one part of the RE innovation. As a result, studies that can derive political implications for the systemic RE innovation in the EU are still scarce. In the following sections, the status of the innovation environments of the EU countries and their performances of the exchange of their innovation capacities for the systemic RE innovation through the EU-funded innovation networks are discussed.

3. Data and methodology

This section consists of two parts. The first part describes the data and methodology used for measuring the levels of innovation capacities of each EU country and allocating them into four groups with the comparable levels of innovation capacities. The second part presents the data and methodology employed for investigating the resource exchange behaviors of the EU countries in the related networks.

3.1 Measurement and classification of the innovation capacities

3.1.1 Data description

Considering the elements of systemic RE innovation from the previous literature, relevant data were retrieved from the OECD and Eurostat databases to assess the absorptive and desorptive capacities of the EU countries. The extent of the absorptive capacity of each EU country is measured by seven indicators, which are used to relate to patent applications of RE technologies, government budget on energy R&D, and general R&D foundations for high-technology fields, including R&D expenditure of business enterprise and number of scientists and engineers in high-technology manufacturing and services. Along with the market exploitation dimension, the desorptive capacity of each country is calculated using nine indicators, which are indicative of the level to which a country has market demand and sophisticated infrastructure to apply the RE sources. In particular, the effectiveness of political measures and industrial system can also be seen as a reasonable proxy for measuring the desorptive capacity because they determine the sophistication level of the market exploitation environment. In this regard, indicators, such as tax rate on energy, carbon intensity of the industries, and share of RE in total energy use, are used to gauge the extent of desorptive capacity. The performance indicators, such as patents, carbon intensity, or share of renewables in the market, are calculated not only as the mean records but also the growth in the numbers over the concerned periods for both exploration and exploitation dimensions. The indicators are listed in Table 2.

Table 2 Indicators of absorptive and desorptive capacities of the EU countries

Description	Source
Exploration dimension: Absorptive capacity	
• Patent applications to the EPO. Average number of the patent applications to the EPO per inhabitant. (2003–2010)	OECD
• Growth in the number of patent applications to the EPO per inhabitant. (2003–2010)	OECD
• Patent applications to the PCT. Average number of patent applications filed under the PCT per inhabitant. (2003–2011)	OECD
• Growth in the number of patent applications filed under the PCT per inhabitant. (2003–2011)	OECD
• Public funding for the energy R&D. Average government budget appropriations or outlays on the R&D for Energy by Statistical Classification of Socio-economic Objectives 2007 (Euro) per inhabitant. (2008 and 2012)	Eurostat
• Business R&D expenditure in the high-tech sector. Average R&D expenditure of the business enterprises in sectors of high-technology manufacturing and knowledge-intensive high-technology services (Euro) per inhabitant. (2005, 2006, 2011, 2012)	Eurostat
• Personnel in high-tech sectors. Average number of scientists and engineers in sectors of high-technology manufacturing and knowledge-intensive high-technology services (from 25 to 64 years) per thousand inhabitants. (2008–2012)	Eurostat
Exploitation dimension: Desorptive capacity	
• Tax rate on energy. Average ratio between the energy tax revenues and the final energy consumption calculated for a calendar year. The final energy consumption includes energy consumed in transport, industry, commerce, agriculture, public administration, and households. The different energy products are aggregated based on their net calorific value and expressed in tons of oil equivalent (Euro per tons of oil equivalent). (2003–2012)	Eurostat
• Negative carbon intensity. Average inverse ratio between the energy-related greenhouse gas emissions (carbon dioxide, methane, and nitrous oxide) and the gross inland energy consumption. (2003–2012)	Eurostat
• Decrease in carbon intensity. (2003–2012)	Eurostat
• Average share of renewable energy in the fuel consumption of transport. (2004–2012)	Eurostat
• Growth in the share of renewable energy in the fuel consumption of transport. (2004–2012)	Eurostat
• Average share of electricity generated from renewable sources (percentage of gross electricity consumption). (2004–2012)	Eurostat
• Growth in the share of electricity generated from renewable sources. (2004–2012)	Eurostat
• Average share of renewable energy in the gross final energy consumption. (2004–2012)	Eurostat
• Growth in the share of renewable energy in the gross final energy consumption. (2004–2012)	Eurostat

3.1.2 Indexing and k-means clustering

The absorptive and desorptive capacities of each country are summarized in two composite summary indexes to measure its ability for systemic RE innovation. The calculation of indexes follows a methodology of Innovation Union Scoreboard of the EU (Hollanders and Es-Sadki, 2014) through six steps. First, outliers are identified and replaced. Positive outliers are identified as those relative scores that are higher than the mean across all the EU countries plus two times the standard deviation, whereas negative outliers mean that those relative scores are smaller than the mean across all countries minus two times the standard deviation. These outliers are replaced by the respective maximum and minimum values observed over the entire years and all the countries. Second, a reference year is identified for each indicator based on the data availability for all the EU countries, for which data availability is at least 75%. If the data for a year-in-between are unavailable, they are substituted by the value for the previous year. Third, the maximum and minimum scores are determined. The maximum score is the highest relative score found for the entire period within all countries excluding positive outliers. Similarly, the minimum score is the lowest relative score found for the entire period within all the EU countries excluding negative outliers. Fourth, the data are transformed, if data are highly skewed. If the skewness of the indicators is above 1, the data are transformed using a square root transformation. Fifth, re-scaled scores of the relative scores for all years are calculated by subtracting the minimum score and then dividing by the difference between the maximum and minimum scores. Sixth, a composite summary index over the entire period is calculated for each country. The indexes previously published usually take an equally weighted average of different indicators. The relative significance of the indicators varies by national priorities, circumstances, and a variety of viewpoints, such as political, economic, and technological ones (Esty et al., 2005; Hollanders and Es-Sadki, 2014). Given the diversity of determinants of the systemic innovation in the EU countries, the composite summary indexes within this research are the unweighted averages of the re-scaled scores of all indicators.

The two types of composite summary indexes are used in this research to conduct a k-means clustering to segment the EU counties into four groups with similar innovation environment. The k-means clustering is a centroid-based clustering model that represents each group by a single mean vector. The k-means algorithms require the number of group “k” to be fixed in advance. Given that four types of innovation environment are defined in the following chapter, the k-means clustering is applicable for this research. Each actor is assigned to a group based on the distance of that actor to the group mean, which means that the groups always assign an object to the nearest centroid.

3.2 Analysis of the resource spillover behaviors

A social network analysis (SNA) on the country-level networks formed by the EU-funded innovation projects is conducted in this study. Although the actual interactions in the EU-funded innovation projects occur at the organizational level, the SNA is performed at the country level because of the following reasons: First, the innovation outcomes of the project conducted are related to the innovation environment in the participating country, as influenced by its partnership pattern, apart from the mere number of initiated projects or geographical conditions of the country. For example, the position of a counterpart's country in the EU-funded international network can determine the country's influence on the entire network as well as its access to resources. Second, the country-level analysis can help policy makers further improve related policies or programs at the national or EU levels in the desired directions. Detailed information on the collaboration dependency in resource flows among countries enables them to diagnose the role of countries in those flows and develop appropriate strategies to cope with their jurisdictions.

3.2.1 Data description

The data on the participating countries in each consortium of the project are collected and aggregated to observe partnership distribution at a macro level. The collected data on project participants are converted into two-mode binary network data of actor by event for the SNA, and the projects are interpreted as an affiliation relationship. The binary two-mode network data, which represent the relationship between participating countries, are prepared in the form of a matrix, as shown in Table 3. If a country participates in a particular project, the relationship is recorded as 1. If it is not involved in a project, the relationship is marked as 0. These two-mode binary network data are converted into one-mode valued network data of actor by actor to simplify the data analysis and apply a wide range of SNA techniques. The relationship matrix in this one-mode valued network represents the intensity of networking between two countries through projects. Self-ties are excluded throughout the converting process.

Table 3 Example of two-mode binary network data

	Project 1	Project 2	Project 3	Project 4	…
Country 1	0	1	1	0	…
Country 2	1	0	0	0	…
Country 3	1	1	0	1	…
Country 4	1	0	0	1	…
…	…	…	…		…

Projects funded by the FP programs, which aimed to support the technology R&D, and IEE programs that are supported the non-technological innovation activities, are investigated in this study to cover both dimensions of the systemic RE innovation. Both programs were initially launched in 1984 and 2003, respectively. Although the sixth FP (FP6) officially began in 2002, its projects on RE topics started to be funded in 2003 because of the time consumption in the negotiation and preparation phases. The first IEE (IEE1) was officially launched in 2003, but the funding periods of projects actually began in January 2005. The seventh FP (FP7) and the second IEE (IEE2) were officially operated from 2007 to 2013, even though the actual start dates of their projects began in 2008. In both programs, RE-related topics take the largest portion in terms of project number, accounting for over one-third of the total projects in general energy fields except for nuclear energy. These two programs expired at the end of 2013 and have been integrated under the Horizon 2020 program from 2014.

Table 4 shows the project data obtained from the CORDIS and IEE databases, which are the official data sources that provide information. Topics on fuel cell and hydrogen are excluded within this research.

Table 4 Description of project data applied for the network analysis

	Funding period I		**Funding period II**	
Project start date	2003–2007		2008–2013	
No. of projects / countries	219 / 51		286 / 57	
Targeted program	FP6	IEE1	FP7	IEE2
No. of registered projects / countries	105 / 49	114 / 31	154 / 57	132 / 31
Funding category	1) Clean energy, in particular renewable energy sources and their integration in the energy system, including storage, distribution, and use 2) Alternative motor fuels 3) New and advanced concepts in renewable energy technologies	1) All projects under ALTENER (renewable energy) 2) Projects on alternative fuels and vehicles under STEER (transport)	1) Renewable electricity generation 2) Renewable fuel production 3) Renewables for heating and cooling	1) All projects under ALTENER 2) Projects on alternative fuels and vehicles under STEER

The collected data are categorized into two periods, the registered start dates of which are before and after 2008. Period I covers FP6 and IEE1, and Period II applies to FP7 and IEE2. The project data from two separate programs for each period are merged as a single network, and the performances of partnership network in Periods I and II are compared to analyze the dynamics of resource spillover over time.

This ex-post integration of the project data from different sources is caused by the facts that both programs have similar number of projects for each period and their project consortiums are formed on the same principle. For example, international networking is encouraged in both programs by demanding different sets of partners with specific knowledge, capacities, roles, and geographical locations. In general, both programs are based on the same funding principle that they require minimum of three independent partners from three different eligible countries in a project consortium. On average, the FP and IEE programs exhibit 23% of correspondence in terms of their participating organizations in the projects on RE topics over eleven years. In other words, the partnership networks of the two programs can be regarded as being connected through these linkages. Both programs have been recently integrated under the Horizon 2020 program to link the entire innovation stages. As a result, the dual execution of both exploration and exploitation activities is inevitable under the current and future funding direction of the EU.

3.2.2 Social network analysis

A social network is a set of social actors and the connections among them. It consists of nodes and links; each node signifies an individual or a group, and the link represents relationships between the individuals. The SNA is a widely accepted method to scrutinize the structural features and dynamics of partnership relations (Batallas and Yassine, 2006). Unlike purely descriptive statistics, the SNA offers valuable data that can be used to assess the qualitative aspects of the interaction strategies between countries. For example, a country can be an active participant of programs in quantitative terms but may exert considerably less influence on the entire network in terms of the resource spillover when a country has an ineffective partnership structure. The investigations into the networking properties on how loosely or closely the actors are connected to share resources and capacities may deepen the understanding on the strategic objectives pursued by the actors in the network (Gilsing et al., 2008).

This chapter describes the several properties of SNA based on the Borgatti et al. (2002), which are particularly pertinent to examining the resource spillover behaviors under the EU programs. UCINET and NetDraw are employed as analysis tools to interpret and visualize the networking structures.

A. Basic characteristics

The basic characteristics of network connections are described by quantifying their structural features. The SNA measures that calculate the network structure include size (the total number of actors in a network), density (the ratio of actual connections to possible existing connections within the network), distance (the average number of relations between actors), diameter (the influence scope of the actors), and average clustering coefficient (the mean of the density of the open neighborhood of all actors).

B. Centralities

The measurement of the centrality of each actor is crucial to understanding the network comprehensively (Batallas and Yassine, 2006) because the location and relation of an actor to other actors are strategically important in affecting the structure and functionality of the entire network. Generally, the intensity of organizational connectivity varies by actor because more intensively connected actors exist in the network. The most widely known centrality measure is degree centrality, which means the absolute degree of direct relationships that the given actor has with others (Freeman, 1979). The central actor can gain more opportunities to absorb the critical resource and eventually achieve enhanced performance and competitive advantage by reaching direct connections with more individuals in the network (Liu, 2011).

C. E–I index and density between groups

Given a partition of a network into a number of mutually exclusive groups, an E–I index gauges the external openness of each actor or each group. The index calculates the number of ties external to the groups minus the number of ties that are internal to the group divided by the total number of ties. This value can range from 1 to −1. With the E–I index, the tendency of partnership strategies between individual actors, groups, or the entire network can be measured.

Unlike the overall network density, which considers all types of ties as a property of the total network, the density can be measured within and between the given partitions. For example, the density can be measured as the total of all values divided by the number of possible ties within or between the partitions. The density between the partitions differs from the E–I index in that the density shows the relationship intensity of the specific pair of the groups, whereas the E–I index indicates the proportion of the internal relations to the aggregated total of all the external relations, regardless of which external partition they are.

4. Analysis

The analysis section consists of two parts. In the first part, the levels of innovation capacities of each EU country are calculated and categorized into four groups with the comparable levels of innovation capacities. In the second part, the resource exchange behaviors of the EU countries are investigated.

4.1 Measurement of the systemic innovation capacities

Tables 5 presents the composite summary index of the absorptive or desorptive capacity of all the EU countries. As presented in the preceding chapter, the absorptive capacity index is measured based on the indicators that are specifically related to the overall capacities of the country to explore and absorb resources required for the R&D activities of RE technologies. By contrast, the desorptive capacity index is calculated by gauging the indicators that are pertinent to the overall capacity of the country to deploy the R&D results in the market based on the market demands and readiness.

Table 5 Innovation capacity indices of EU countries

Country	Absorptive capacity index	Desorptive capacity index
Austria	0.61	0.74
Belgium	0.49	0.50
Bulgaria	0.20	0.32
Croatia	0.22	0.41
Cyprus	0.10	0.30
Czech Rep.	0.23	0.51
Denmark	0.81	0.81
Estonia	0.17	0.54
Finland	0.77	0.52
France	0.52	0.54
Germany	0.68	0.59
Greece	0.23	0.48
Hungary	0.17	0.46
Ireland	0.60	0.53
Italy	0.34	0.63
Latvia	0.19	0.50
Lithuania	0.15	0.38
Luxembourg	0.50	0.31
Malta	0.23	0.19
Netherlands	0.53	0.52
Poland	0.14	0.42
Portugal	0.24	0.57
Romania	0.12	0.51
Slovakia	0.13	0.44
Slovenia	0.31	0.49
Spain	0.43	0.52
Sweden	0.70	0.86
UK	0.45	0.47

This research introduces groupings of EU countries to understand the characteristics of the innovation environments in these countries and to observe the similarity among such environments, given that each environment provides different conditions for systemic RE innovation. In accordance to the elements of systemic RE innovation identified above, this research proposes four groups divided by two dimensions of technology exploration and market exploitation. The groups are specified as ambidextrous, explorative, exploitative, and blocked environments, as shown in Figure 1. The ambidextrous environment refers to an environment where the levels of both the absorptive and desorptive capacities for promoting RE innovation are relatively high. This environment has also reached a certain point where uncertainties in both technology exploration and market exploitation are limited. The explorative environment refers to an environment where actors tend to excel at exploring new technological resources and transforming those resources into novel technological solutions despite the limited level of market sophistication. By contrast, the exploitative environment refers to an environment that possesses a superior market innovation base for exploiting developed technologies, including societal and institutional supports or advantageous geographical conditions. However, this environment remains relatively unsophisticated for systemic RE innovation because of the insufficient levels of the absorptive capacity for technological exploration. The blocked environment refers to an environment where neither the incentive for advancing RE technologies nor any significant market advantages for utilizing RE sources exist.

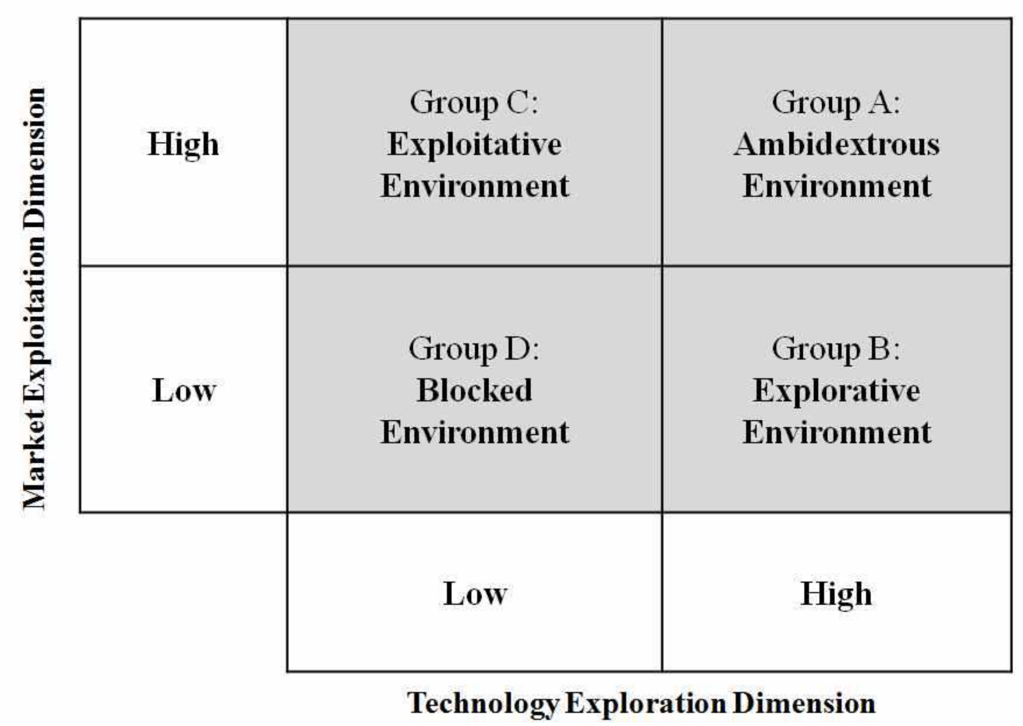


Figure 1 Segmentation of RE innovation environments

Using composite summary indices, k-means cluster analysis is performed to allocate the countries into the four groups. The initial cluster centers are determined through SPSS. Each country is assigned to a group depending on the distance of that country to the centroid of the group. Through iteration, the group centers are optimized, and the memberships of the groups are determined. Table 6 shows the iteration history for this analysis, which is six times in total. The final group centers and the member countries of each group are indicated in Table 7.

Table 6 Iteration history*

Number of iterations	Change in group centers			
	Group A	Group B	Group C	Group D
1	0.143	0.151	0.105	0.106
2	0.000	0.034	0.061	0.012
3	0.000	0.000	0.011	0.012
4	0.000	0.000	0.015	0.017
5	0.000	0.000	0.010	0.014
6	0.000	0.000	0.000	0.000

* Convergence is achieved because of a small or no change in the group centers. The maximum absolute coordinate change for any center is 0.000. The minimum distance among the initial centers is 0.362.

Table 7 Final group centers

Category	Group A	Group B	Group C	Group D
Absorptive capacity	0.714 (High)	0.503 (High)	0.224 (Low)	0.168 (Low)
Desorptive capacity	0.702 (High)	0.485 (Low)	0.522 (High)	0.351 (Low)
Group members	Austria Denmark Finland Germany Sweden	Belgium France Ireland Luxembourg The Netherlands Spain UK	Czech Rep. Estonia Greece Hungary Italy Latvia Portugal Romania Slovenia	Bulgaria Croatia Cyprus Lithuania Malta Poland Slovakia
Number of members	5	7	9	7

4.2 Analysis of the resource spillovers

This section analyzes the structural embeddedness of the EU countries in the EU-funded network to manage how EU countries collaborate in complementing limited resources and capacities for systemic RE innovation.

A. Overall partnership structure

Table 8 illustrates the overall structure of the partnership network of all the countries under the EU-funded innovation programs. The partnership networks under the EU-funded innovation programs tend to be small and dense. The scope of influence of the countries is narrow, considering the short distance and diameter of the network. The whole network in each period consists of one component. According to the overall density of this valued network, the average strength of the relationship between any two countries in the network increases with time. Given that the average clustering coefficients are higher than the overall densities in both networks, the networks are expected to cluster around specific actors. The growing clustering coefficient index suggests that such relationship hierarchy intensifies with time. The E-I index presents the external openness of the whole network given the groups of the innovation environment. The overall E-I indices signify that the countries forge 3.73

times more partnerships that are external to the groups than partnerships that are internal to the groups in the first period, which accounts for 4.60 times in the second period. The results suggest that the countries participating in the networks tend to develop innovation capacities through partnership with other countries with different innovation backgrounds, which is a tendency that has increased over time.

Table 8 Overall structure of country-level partnership networks: Period I vs. Period II

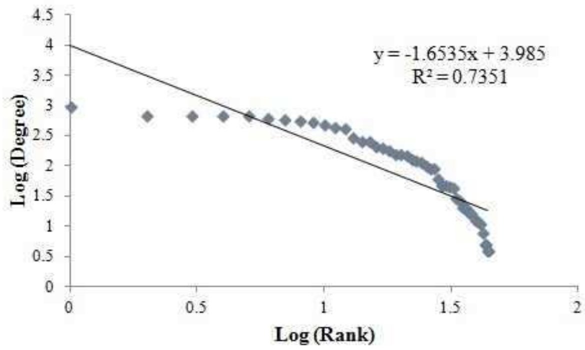
Network Properties	Period I (2003–2007)	Period II (2008–2013)
Number of projects	219	286
Number of countries	51	57
Overall density: average tie strength (std. dev)	4.03 (9.57)	4.42 (11.21)
Component	1	1
Average distance	1.49	1.53
Diameter	3	3
Average clustering coefficient	13.22	16.34
Overall E-I index	0.577	0.643

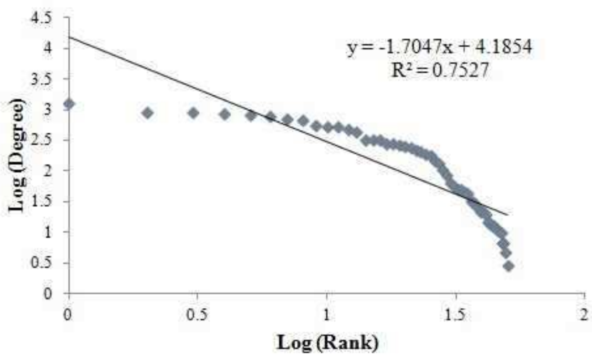
B. Hierarchy in the relationship

This research analyzes the relational hierarchy of the EU-funded innovation networks to understand the overall resource flows throughout the network and the collaboration dependency of the countries in the network. First, the relational hierarchy can be analyzed by measuring the distribution of the degree centralities in the networks. The distribution of the degree centralities can vary from flat to inclined distribution. A more steeply sloped degree distribution means that a higher hierarchy exists in the degree of countries. If *d* is noted as the degree of a particular node *n*, the node degrees d_n can be classified from the largest to the smallest by referring to a rank-size rule. The degree distribution is then drawn on a log-log scale as follows. While d_n* is the rank of the node n in the degree distribution, C is a constant and a < 0 is the slope of the distribution or equivalently.

$$d_n = C(d_n*)^a \qquad (1)$$

$$log\ (d_n) = log\ (C) + a\ log\ (d_n*) \qquad (2)$$





Period I (2003–2007) Period II (2008–2013)

Figure 2 Degree distributions in the networks: Period I vs. Period II.

Figure 2 depicts the slops of the degree distribution in both networks. The network in the first period presents a strong inclination in the degree distribution, which signifies the cohesiveness of the core group. In the second period, the network shows a more steeply sloped degree distribution. These findings imply that the connectivity of the EU-funded network for systemic RE innovation is highly controlled by a few important countries that occupy the favorable positions in the network and that the concentration of the relationships around a few actors intensify with time. The results contradict network visualization but conform to the aforementioned increasing clustering coefficient.

The collaboration dependency and hierarchy of the positions in the network can also be measured through preferential attachment. A network can evolve through the entry of a new actor that connects to other participants either through random or preferential attachment (Barabasi et al., 2002). Random attachment means that new comers randomly connect to other participants with no particular preference in terms of structural position, which generates a rather flat hierarchy of degrees in the network. In the course of preferential attachment, the new actors that enter the network more probably connect to a degree-central actor. In this case, the network exhibits an inclined hierarchy.

Figure 3 suggests the existence of preferential attachment in the networks for systemic RE innovation. First, the distribution of the degrees of the participating countries during the first period is investigated. Second, the number of new links established in the second period is identified. Third, the relative probability of the new links is calculated by the ratio between the proportion of the new links added to the countries with k previous links and the proportion of the countries with k previous links to all the countries present in the network immediately before the addition of the new link (Barabasi et al., 2002). The countries with a high level of degree centralities in the first period obtained a disproportionately higher number of connections from the newcomers in the second period. For example, countries with up to 100 previous links, which represented 52.94% of all the countries participating in the first network, acquired 21.67% of all the new connections established in the second period. However, those countries with more than 900 links accounted for only 1.96% of all the countries in the first period but attained 10.83% of all the incoming countries in the second period. The more new entering countries are connected to highly connected countries, the higher the increase in their payoffs because of the benefits of reciprocal knowledge accessibility.

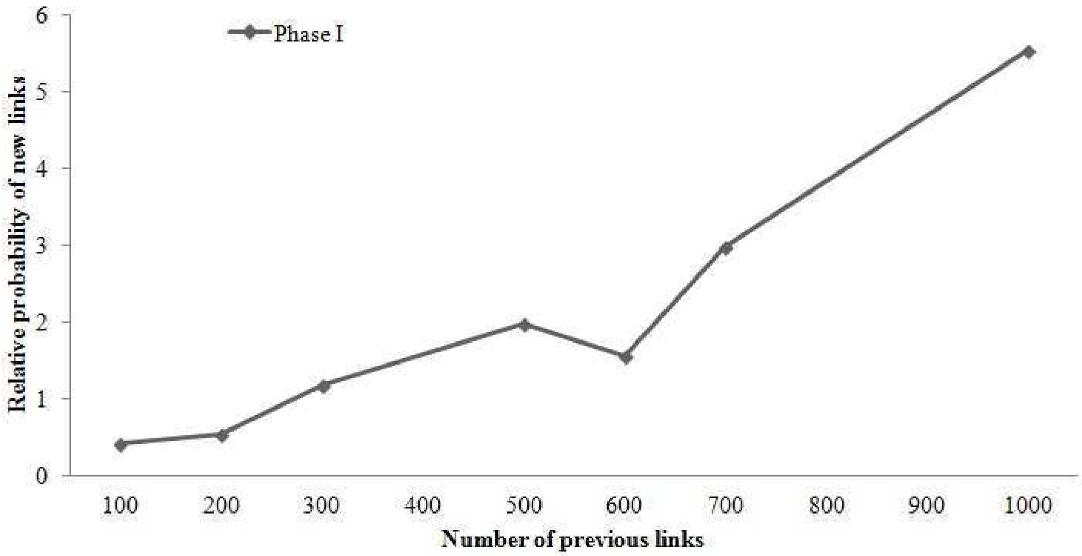


Figure 3 Preferential attachment

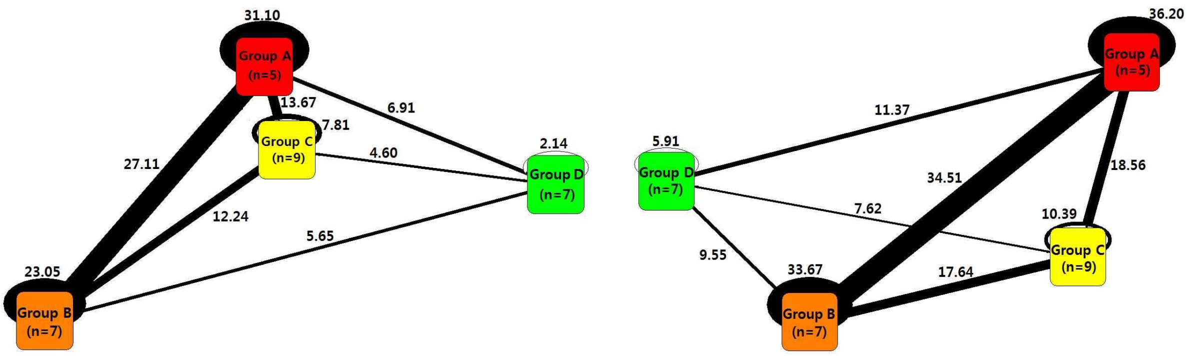
Table 9 ranks the ten most degree-central countries in both periods. The countries listed are the most influential countries in the hierarchy under the EU-funded networks for the systemic RE innovation. Both lists are composed of the countries from the EU region, the majority of which belong to Group B with advanced absorptive capacity. The other half consists of three countries from Group A, including Germany, Austria, and Sweden, and two countries from Group C, including Italy and Greece. Although the compositions of both lists are coherent and consist of identical countries, the rankings of the individual countries have slightly changed. For example, the ranking of Belgium from Group B has notably increased from ninth place to fourth place over time. Italy from Group C also shows a remarkable presence as the second most degree-central country in the second period. In general, the core of the networks is mainly occupied by the EU countries with superior absorptive capacities over the observed period.

Table 9 Centrality rankings: Period I vs. Period II

Rank	Country	Group	Value	Rank	Country	Group	Value
1	Germany	1	938	1	Germany	1	1291
2	Spain	2	687	2	Italy	3	956
3	Italy	3	675	3	Spain	2	941
4	UK	2	672	4	Belgium	2	899
5	France	2	668	5	UK	2	855
6	Netherlands	2	604	6	France	2	808
7	Austria	1	585	7	Netherlands	2	741
8	Greece	3	547	8	Austria	1	706
9	Belgium	2	528	9	Greece	3	574
10	Sweden	1	480	10	Sweden	1	550

C. Resource exchange behaviors among the EU countries

This section investigates the collaboration dependency and pattern of resource spillovers among the EU countries or groups of the EU countries in the network. Given the four partitions of the EU countries based on their innovation capacities, Figure 4 and Table 10 present the partnership relations within and between the groups. The relationship intensities within and between the groups become generally greater in the second period than in the first period. This is also is in line with the increased overall density by time In analyzing the interactions between the individual groups, the internal density within Group A exhibits the highest value in both periods. This value is above all the other densities within or between any groups in the whole network. In both periods, the partnership density between Groups A and B is slightly lower than the internal density of Group A, followed by the density between Groups A and C, which is nearly half of the previous ones. The density between Groups A and D is the weakest. For Group B, the collaboration density with Group A is the greatest. However, the internal density within Group B ranks second place in this case, followed by those within Groups C and D. A similar tendency is also observed in the other cases.



Period I (2003–2007) Period II (2008–2013)

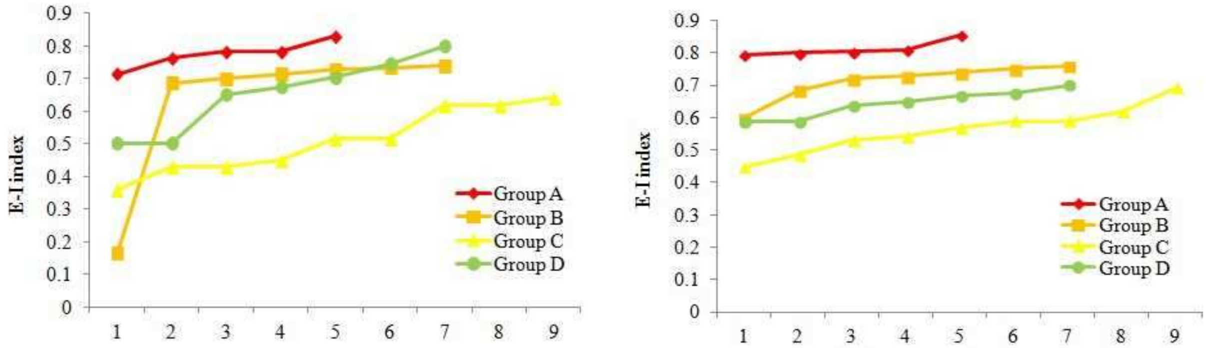
Figure 4 Densities between groups: Period I vs. Period II
Dark blue: Core block, Light blue: Semi-core block
Size of node: internal density, Size of line: between density

Table 10 Density by groups (2003–2013)

		Group A	Group B	Group C	Group D
Period I	**Group A**	31.10	27.11	13.67	6.91
	Group B	27.11	23.05	12.24	5.65
	Group C	13.67	12.24	7.81	4.60
	Group D	6.91	5.65	4.60	2.14
		Group A	**Group B**	**Group C**	**Group D**
Period II	**Group A**	36.20	34.51	18.56	11.37
	Group B	34.51	33.67	17.64	9.55
	Group C	18.56	17.64	10.39	7.62
	Group D	11.37	9.55	7.62	5.91

The result indicates that the resource exchange for the systemic RE innovation in the EU-funded networks is driven more by the superiority of the innovation capacities of the collaborators than by the similarity in their innovation environments. For example, the density is the highest for all groups when they collaborate with Group A, followed by the density of partnerships with Groups B, C, and D. Even the countries of Group A have the densest partnership intensity with members of their own group. All the other groups except for Group A show denser relations with external partners than with internal members. Another clear finding from this analysis is that the absorptive capacity of a country is a more significant determinant of partner selection than desorptive capacity because all the groups show more intense relationships with Group B, which has an advanced absorptive capacity for technology exploration activities than Group C, which has a desorptive capacity for market exploitation activities. The likelihood of partnership is higher between countries with similar levels of absorptive capacity than those with dissimilar levels of absorptive or desorptive capacity. Comparing the relationships among Groups A, B, and C, the collaboration intensity between Groups A and B or between Groups A and C is higher than that between Groups B and C. Group B is more willing to collaborate with Group A sharing a similar explorative backgrounds than with Group C having no intersection in terms of the innovation capacity. Group C also shows higher readiness to collaborate with Group A than with Group B. Therefore, countries with a certain degree of ex-ante innovation capacities that are similar to those of their counterparts can successfully internalize their external resources and complement their in-house capabilities (Gilsing et al., 2008).

In addition to the group density values, Figure 5 presents the external openness of each EU country given the four groups of the innovation environment. All the EU countries exhibit more outward relationships than inward ones, thereby showing positive E-I indexes. In the first period, the countries from Group A significantly show the greatest external openness. However, the graph does not provide a clear tendency that the external openness of the EU countries is distinctly affected by their innovation environment. By contrast, the external openness in the second period is likely to have different tendencies per country group. First, the countries of Group A show the greatest tendency to resort to external collaboration, although these countries are assumed to be significantly independent from external knowledge. Although the internal density in Group A is above all the densities between any other counties in the entire network, its E-I index is the highest. The E-I index of this group exceeds those of all other groups in terms of the aggregated total of all external relations, regardless of which external group they belong to. Second, Group B shows the second significant E-I index trends. Third, the countries in Group D rank third place and exhibit a higher level of index values than Group C.



Period I (2003–2007) Period II (2008–2013)

Figure 5 E-I indexes by innovation environment: Period I vs. Period II.

Given that the partnership created by the joint project, such as the EU-funded innovation project, is an undirected and mutual relationship, the E-I index in such network can be interpreted from two different perspectives. On the one hand, the E-I index is viewed as a measure of outside-in strategy, which focuses on external values, resources, and opportunities. From this point of view, the countries in Group A with a high level of E-I index seek ideas from different innovation environments and introduce them into their own environments. Although these countries are expected to be less dependent on collaboration, they may still be interested in collaborating with other innovation environments to reduce costs of innovation activities, expand the market, and facilitate the process of joint knowledge creation. In the case of the countries from Group B with the second highest E-I index in the second period, motives for external partnership can be generated to reduce the uncertainty about the market deployment of RE technologies. The cross-border alliance can enable the countries in this environment to overcome the lack of self-sufficiency of vulnerable RE sources and achieve economies of scale in the innovation activities by reducing the time span from investment to market introduction (Charles et al., 2009; EC, 2013; Gullenberg et al., 2014).

On the other hand, the E-I index can exemplify the inside-out approach, which builds on the internal orientation focusing on existing resources and strengths. Based on this perspective, the countries from Group A with a high level of E-I index tend to pursue a local search to enhance their own capacities and achieve an effective system within the innovation environment (Chesbrough, 2011). Moreover, the E-I index can be viewed as a measure of the attractiveness of a country as a collaboration counterpart conceived by the countries in other innovation environments. These countries enjoy a stronger bargaining position in their partnerships because of their ownership of superb innovation capacities. In the second period, the absorptive capacity for technology exploration is supposed to be a more influential criterion for the partner choice than the desorptive capacity because the E-I index of Group B is more superior to that of Group C. This implication is also in line with the findings on the partnership densities between the groups, as shown in Table 10. The findings from the second period imply that the inside-out perspective is more appropriate to interpret the results of the present analysis because of the following reasons. First, the countries with a high level of E-I index are those that have already excelled at exploring and absorbing the knowledge, such as Groups A and B, and need not to be highly reliant on external knowledge. Second, the countries of Group C are supposed to be ready for external partnerships to complement their lack of desorptive capacity. However, the low level of E-I indexes of these countries indicates that such complementary relationship is still limited and that the partnership for systemic RE innovation is significantly driven by the superiority of the innovation capacities of the counterparts.

7. Implications and Discussion

This research measures the innovation capacities of the EU countries in the RE area and examines the determinants of the resource exchange among these countries. The innovation environments of the EU countries are also characterized based on their absorptive and desorptive capacities. The results from SNA suggest that the partnership is unevenly distributed across the network but concentrated around a few EU countries with high levels of absorptive capabilities. Therefore, organizations in the EU countries mainly focus on the absorptive capacity of their counterparts in the process of partner selection. The imbalance of partnership distribution can affect the power relations and collaboration strategies between actors in terms of resource mobilization. In this regard, the findings and issues from this research can give implications at both the participant and policy levels.

At the participant level, the understanding on innovation environment or structural position of a counterpart can influence its partner selection in building a project consortium because these factors determine the innovation outcomes and innovation path of a project. Connecting to the organizations in the countries with better innovation conditions or central position in the network can be effective in acquiring the valuable innovation capacities. For example, when collaborating with the organizations in countries with less advanced innovation environments, the innovation activities must pursue safe and moderate strategies in which the expected return does not outweigh the potential risk (Walsh, 2012), such as involving more governmental or institutional supports to finance the innovation activities. The participating organizations can eventually save time and resources with a greater chance of systemic RE innovation and benefit from reducing their risk of resource and capability investment through a better understanding of the environment of the counterpart they are investing in.

At the policy level, the findings from this research can mainly help policy makers of the member states to consider which policies best encourage systemic RE innovation within their jurisdictions and to adapt their political strategies to their respective innovation environments. For example, countries placed in the least-central blocked environment can pursue the strategy of capability sharing with other countries to internalize the resources, competencies, and tacit knowledge of their partners and uplift their own technological and institutional foundations to levels at par with those of advanced countries (Kang and Park, 2013; Liu and Liang, 2013; Ru et al., 2012; Zhou et al., 2012). However, the lack of innovation capacities prevents other advanced countries from building partnerships with countries in the blocked environment. In comparison, countries in the exploitative environment can adopt partnership strategies to exchange technological knowledge and share risks associated with R&D with countries with superior technologies. In this process, the partnership can involve strategies of technical assistance, outsourcing, or licensing because the technological superiority of these countries is less dominant than that of the counterparts (Walsh, 2012). These insights can aid policy makers to design additional policies that attract other countries with better innovation conditions into the partnership, particularly under the new funding program, namely, Horizon 2020, and future collaboration mechanisms under the RE directive of the EU.

Second, this research enables policy makers at the EU level to optimize the collaboration dependency in resource and capability flows under the EU-funded innovation programs and develop succeeding policies or programs in the desired directions. In the systemic RE innovation network of the EU, the information and resource flows are rather dominated and controlled by a small number of central countries with advanced absorptive capacities. This finding implies that the previous policies of the EU have been ineffective for market exploitation and less relevant to the systemic innovation connecting the innovation lifecycle. In the Horizon 2020 program, particular attention should be given to promote the dual achievement of technology exploration and market exploitation in the RE sector through international partnership. This effort facilitates the utilization of the innovation potentials of the EU countries, particularly those in the exploitative environment, which have favorable market infrastructure but underdeveloped technological capabilities.

The unequal distribution of partnership opportunities can be mitigated by introducing political and economic measures that fund the innovation activities and build the capacities of the neglected countries, particularly the countries with no incentives for both technology exploration and market exploitation. The uneven concentration of partnerships is particularly caused by the preference for low-risk investment in RE innovation activities. In this regard, the international resource spillovers decrease investment costs in energy R&D in the advanced countries, the economies of which are exposed the most to the international exchange of ideas and have greater benefits in terms of potential investment savings (Bosetti et al., 2008). Consequently, free-riding effects are also expected among the countries with high levels of absorptive capacities. To minimize these structural pitfalls and ineffectiveness, this research suggests introducing top-down measures to the current Horizon 2020 funding scheme and bottom-up measures to the capability building programs of the non-innovative countries, which lack sufficient R&D and market infrastructure to attract resources and capabilities from other countries. As for the top-down measures, the introduction of quota systems or differentiated eligibility of countries to the Horizon 2020 funding scheme, specifically for areas requiring the systemic approach, can mitigate the uneven concentration of power relations and innovation capacities in a few countries. However, the top-down provision of incentives for those countries is not only confined to merely raising the financial grants dedicated to their participation in Horizon 2020. In a wider context, the support is more about increasing their opportunities to take part in the innovation projects and aiding them to secure a strategic role and position in the network. As for the bottom-up measures, the innovation fundamentals of the underrepresented countries can be established through other support schemes of the EU, such as structural or cohesion funds, which intend to narrow the development disparities and connect energy infrastructure among regions and member states. Competitiveness is likely to rise in the long run if these funds can be properly invested in developing the scientific and market infrastructure of these countries. However, the structural funds cannot fully supplement the resources attainable through the Horizon 2020 scheme because the mobilization of these funds is not strategically planned from the macro point of view but usually decided by the member states themselves. Moreover, developing the RE innovation system is not the primary issue of those funds (EU Expert Group, 2010). In addition, other types of political measures need to be developed to support the internalization of asymmetric resource spillovers and capacity complementarities within the EU, particularly for those countries insufficiently benefiting from the existing funding schemes.

In summary, the contribution of this research can be specified as follows. First, this research improves the existing literature on the innovation in the RE area by adding the systemic aspect. Second, this research diagnoses the current state of the systemic RE innovation environment and resource spillovers of the EU countries. Third, this research provides information on the innovation environment of each country, which influences the attractiveness of the counterpart organization in building a project partnership in the RE sector. Finally, this research indicates which political and institutional measures need to be adopted for the improved complementarities of the systemic innovation resources and capacities within the EU, particularly under the current Horizon 2020 scheme.

Despite the contributions of this research, its limitations include the difficulty of empirically verifying the relationship between innovation capacity and resource spillovers for systemic RE innovation. Aside from the network properties, various additional variables should also be considered in analyzing the factors that influence the resource exchange performance of the EU-funded innovation projects. A regression analysis is valuable in future research to clearly examine the influence of various interrelated factors on the success of projects or partnerships for systemic RE innovation. In addition, the present research focuses only on two dimensions to derive four distinct categories of the systemic RE innovation environments. Considering that the environmental landscape is far more complex, other dimensions can also be considered to provide enough specific foundation to elaborate the characteristics and strategic options of the systemic RE innovation. However, the organization is the actual actor conducting the networking process. The means of partnership formation should also be adjusted according to the technical and institutional backgrounds and characteristics of each participant. Thus, analyzing the networks at the organizational level in future research can clarify the structural features of the innovation program of the EU in the field of RE and the main organizations that lead the evolution of systemic RE innovation in the EU.

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