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Open innovation in Power & Energy: Bringing together government policies, companies' interests, and academic essence.

Abstract

The Power and Energy (P&E) sector needs to respond to several challenges fostering investments in research and development. According to the Open Innovation (OI) paradigm, key stakeholders like utilities, vendors, laboratories, universities etc. should take advantage of external knowledge to improve their innovation performance. Several studies have demonstrated that firms adopting the OI paradigm are more likely to innovate. Despite the interest of P&E firms in enhancing their innovation capabilities, surprisingly few articles (usually case studies) described the implementation of the OI paradigm in P&E firms. This article fills the gap by identifying the key drivers that encourage a firm in the P&E sector to embrace the OI paradigm. The authors adopt a hybrid research approach collecting evidence from the literature and through a multiple case-study analysis involving seven British firms and universities operating in the P&E industry. As the drivers of OI have mutual influence, this article describes them with a fuzzy cognitive map. Finally, the authors identify appropriated policies to enhance the OI adoption and, consequently, the sustainability of innovation in the P&E sector. A salient research agenda closes the paper.

Keywords: Open innovation, power and energy, collaboration, fuzzy cognitive map, cross-case study, patents

Section category: Technological Change

1 Introduction

In the last decades, technological breakthroughs (such as Google's search engine, voice over IP telephony, Apple's iPod, music streaming, etc.) have overturned their respective industries (Bers, Dismukes, Mehserle, & Rowe, 2012). Such technological breakthroughs can be considered both inventions and innovations. Indeed, while inventions can be defined as the creation and establishment of something new, innovations are inventions that become economically successful and earn profits (Erwin & Krakauer, 2004; Schumpeter, 1934). Radical inventions such as the cited ones may disrupt established firms' business models or even entire industries, paving the ground for new, and even more radical inventions. The innovativeness of a firm may be associated with the development of inventions (Chang, 2003; Mention, 2011; Revilla, Sáenz, & Knoppen, 2013; Trigo & Vence, 2012; Vega-jurado, Gutiérrez-Gracia, & Fernández-de-Lucio, 2009), with their patentability (Belussi, Sammarra, & Sedita, 2010; Connelly, Dismukes, & Sekhar, 2009; Connelly & Sekhar, 2012; Hussler & Rondé, 2009; van de Vrande, Vanhaverbeke, & Duysters, 2011) or with their market success (Czarnitzki & Thorwarth, 2012; Faems, De Visser, Andries, & Van Looy, 2010; Kuittinen, Puumalainen, Jantunen, Kyläheiko, & Pätäri, 2013; Leiponen, 2012).

Traditionally, the technological innovation in Power and Energy (P&E) firms is mainly ascribed to internal Research and Development (R&D) (Noailly & Ryfisch, 2015). Typical P&E firms had (and still have) laboratories and research centers where their personnel is engaged in R&D activities. External sources of ideas, knowledge, and innovation - such as universities and research institutions - are limited to a supplemental role aimed to fill the perceived gaps. Nevertheless, one of the core characteristics of modern radical innovations is their interconnectedness across organizations, disciplines, industries, and national boundaries, which makes them emerging not from a single source but from complex interactions among different players (Bers et al., 2012). Furthermore, promoting a purposive collaboration among firms and other players in the innovation ecosystem is likely to improve the R&D productivity (Ili, Albers, & Miller, 2010). This may have a huge effect on energy policies considering that the annual R&D investment for the P&E sector in OECD countries is about 20 billion USD (International Energy Agency, 2013).

The idea, initially developed by Henry Chesbrough that "*firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology*" (Chesbrough, 2003, p. xxiv) has spread and evolved, laying the foundations for a new epistemic community that has formed around the concept of Open Innovation (OI) (West, Salter, Vanhaverbeke, & Chesbrough, 2014). According to this community, firms are becoming increasingly aware of the abundant underlying knowledge landscape. Firms need to integrate their internal R&D efforts and to purposely manage their outbound flows of knowledge and technology (Henry W. Chesbrough, 2006). Table 1 summarizes the main novel characteristics of the OI paradigm with respect to the closed innovation paradigm.

TABLE 1 ABOUT HERE

Firms can find fertile grounds for OI in their customers, suppliers and competitors, universities, private or public R&D laboratories, etc. (Sofka & Grimpe, 2010). To take full advantage of the OI paradigm, firms must enhance their networking capabilities and their absorptive capacity, i.e. the ability to exploit external knowledge (Cohen & Levinthal, 1990). The striking success of the OI paradigm in literature is probably related to the vast amount of research linking OI with improved innovation performance (Greco, Grimaldi, & Cricelli, 2015). Empirical studies exploring the effect of OI on innovativeness are fairly distributed among small, medium and large firms. Many of them analysed different industries (Czarnitzki & Thorwarth, 2012; Ebersberger, Bloch, Herstad, & Van De Velde, 2012; Greco, Grimaldi, & Cricelli, 2016; Laursen & Salter, 2006), while others focused on high-tech or R&D intensive ones (Belussi, Sammarra, & Sedita, 2008; Caputo, Lamberti, Cammarano, & Michelino, 2016; Henttonen, Ritala, & Jauhiainen, 2011; Hurmelinna-Laukkanen, Olander, Blomqvist, & Panfilii, 2012).

In this growing body of literature, somewhat surprisingly, very few studies explored OI in the P&E sector. Most of the existing studies (reviewed in section 2.2) qualitatively describe cases about successful implementations of the OI paradigm in P&E companies. Nevertheless, there is no reference to a systemic view of the OI adoption in the P&E sector. This article fills this gap by identifying the drivers of the OI adoption in P&E, describing them synoptically with a fuzzy cognitive map (FCM) and validating the theoretical construct with a cross-case study analysis of the UK *Knowledge Transfer Partnerships* (KTP).

This article is organized as follows. Section 2 describes the methods used to perform the literature review, the multiple case study analysis, and the FCM. Section 3 shows the results, including the main gaps identified in the literature, the benefits associated with the implementation of the OI paradigm in KTP and the FCM. Finally, Section 4 discusses the results, identifies the main contributions of the article, its policy implications and opportunities for future research.

2 Method

2.1 Research approach

As the application of the OI paradigm to the P&E sector is still in its early stages the research approach must be exploratory, focused on the theory building (Easterby-Smith, Thorpe, & Jackson, 2012). As usual in exploratory research, the authors rely on secondary data, mostly qualitative (Brookes & Locatelli, 2015; Tranfield, Denyer, & Smart, 2003). As explained in (Eisenhardt & Graebner, 2007, pp. 26–27) "*theory-building research using cases typically answers research questions that address "how" and "why" in unexplored research areas particularly. By contrast, the research strategy is ill-equipped to address the questions "how often," and "how many," and questions about the relative empirical importance of constructs*". In particular, we followed the research protocol presented in Figure 1, which has been iterative and cyclic. Firstly, we performed a systematic literature review of OI in the P&E sector, which is described in the sub-section 2.2. This allowed the development of a draft FCM. Secondly, taking the lead from the literature review, we analyzed a series of case studies about OI, describing KTP partnerships between UK companies and UK universities. The analysis corroborated existing links and identified additional ones. The new links have been assessed against the generic (i.e. outside the boundaries of P&E firms) OI literature and, if supported, included in the FCM. The FCM was considered final when, looking at the case studies and the literature, the authors reached the theoretical saturation, i.e. "*the point at which incremental learning is minimal because the researchers are observing phenomena seen before*" (Eisenhardt, 1989, p. 545). Actually, every single link and node in the FCM can be targeted as an independent research topic. So, as common for exploratory research, this paper lays the initial background (in the form of the FCM) for future research.

FIGURE 1 ABOUT HERE

2.2 Secondary data analysis

The bibliographic analysis covered the entire population of documents indexed in two relevant literature databases: Elsevier Scopus and Google Scholar. The research queries aimed to identify articles explicitly citing the OI paradigm in either Power or Energy contexts. Firstly, the results of the query on Scopus[1] returned 99 articles. We downloaded and read each of them in order to verify the relevance for the purpose of this study, identifying 22 relevant articles. Subsequently, we extended our research to Google Scholar. The query[2] allowed identifying 20 additional papers not indexed in Elsevier Scopus, 5 of which relevant for the purpose of this study. Figure 2 shows the characteristics of the resulting 27 articles. Remarkably, the majority of the papers described single case studies, whereas only two of them were theoretical in nature. The 27 articles have been clustered according to their level of analysis in the following sections.

FIGURE 2 ABOUT HERE

[1] Scopus query: (TITLE-ABS-KEY ("Open Innovation") AND TITLE-ABS-KEY (power) OR TITLE-ABS-KEY (energy))

[2] Google Scholar query: Find articles

with the exact phrase:	Open Innovation
with at least one of the words:	Energy, Power
where my words occur:	in the title of the article

2.2.1 Theoretical studies

Both the two theoretical studies (González, Galvão, de Falani, Goncalves, & da Silva, 2012; Srikanth, 2011) focus on the wind power industry, achieving similar conclusions. Firms are encouraged to embrace the OI paradigm, especially in the early stages of development of new technologies, such as the development of new materials (Srikanth, 2011) or a new design for wind turbines blades (González et al., 2012). According to Gonzàlez et al., the OI reduces the time to market, expands a firm's market, knowledge, and technological capabilities, improve its efficiency and reduce R&D costs (2012).

2.2.2 Qualitative studies

Qualitative studies include single or multiple case studies, as well as discussion of technologies developed in collaboration with multiple partners.

A key area where OI played and keep plays a key role is energy efficiency. One of the early references is Lindstrand (2009), who discusses the case of the *Energy Square*, a website/platform for OI. Energy Square aimed to develop energy efficiency in paper and pulp industry through a better utilization of technology and research. Similarly, Adamczyk et al. (2011) assess the comments left in an OI platform for energy efficient solutions discovering the different patterns between the comments from different users. Arnold and Barth (2011) evaluate OI ideas in urban energy systems generated over three different ideas competitions. Quite surprising they discover that *"though many of them [ideas] were considered to be only marginally innovative, the majority offered a medium to high degree of innovativeness, and could thus be considered for further elaboration. Some ideas even can be implemented by the users themselves and thus support the bottom-up changes directly."* (p. 362) Ramirez-Portilla *et al.* (2014b) explore the relationship between OI and energy efficiency performance in energy intensive sectors: even if some innovations do not directly aim to improve energy efficiency, they could be considered useful enablers of it. Furthermore, the authors show that more innovative companies also tend to adopt the best available energy-efficient technologies. Yap et al. (2016) look at OI practices in an Indian foundry showing that innovation programs are effective when based on a strategic analysis of the decision context of the target firms. As well, CôrtesPires and Soto Urbina (2009) emphasize the importance of collaborations between firms and universities in the Brazilian Oil & Gas industry, whereas Cagno et al. (2015) explore the positive effect of OI on energy efficiency performance in Italian foundries, and Meller (2011) discusses the P&G sustainability targets driven by OI. Also urban energy efficiency has been targeted by OI initiatives, involving users in the initial phases of idea generation and development (Arnold & Barth, 2011).

OI goes behind energy efficiency. For instance, Sahir et al. (2012) describe how different technologies for the carbon capture in coal plants are the result of the collaboration between firms and universities, in an OI perspective. Hakkim and Heidrick (2008) show how collaborative industry participations and the formation of consortia to perform R&D activities can be extremely successful in the energy sector. Similarly, a multiple case study conducted in South Korea emphasized the importance of joint research with research institutions in inside-out OI and with customers in outside-in OI (Jin-Hyo, Seung-Ku, & Avvari, 2010). OI is also seen as a potential strategy for the development of advanced biofuel technologies (Tanthapanichakoon, 2014). In a recent article, Chesbrough describes General Electric's *Ecomagination Challenge,* a project in which individuals and start-ups were encouraged to submit ideas related to green and renewable energy areas. General Electric invested $140 million in 23 ventures identified at the end of the challenge (Chesbrough, 2012). OI is also seen as a way out from the undesirable effect of excessive outsourcing of core activities, which can weaken the internal R&D capabilities and absorptive capacity (Pellegrini, Lazzarotti, & Pizzurno, 2012). A recent multiple case study (Hess & Siegwart, 2014) analyses R&D alliances between academic spin-offs and a large power industry firm. The authors propose the joint application of real options analysis and a novel technology organizational model to mitigate the risks of OI for breakthrough technologies.

An example of collaboration between firms and universities is the CLEEN consortium, which is owned by 44 firms and research institutions aiming to catalyze international and cross-industrial cooperation in the energy and environmental technology fields (Tolvanen, Ahonen, & Viholainen, 2011). Such collaborative entities are more likely to attract external funds from the government, thanks to the width and quality of the innovation capabilities of the partners. Furthermore, the research expertise and the testing facilities of the research institutions are very helpful in the development of new products (Tolvanen et al., 2011).

Initiatives to support OI in the P&E sector are rising on the web, as in the cited case of the Energy Square (Lindstrand, 2009). Also firms like Repsol, a major Spanish oil company, developed their own internet platforms to gather innovation ideas, taking advantage of individual expertise and creativity (Carbone, Contreras, Hernández, & Gomez-Perez, 2012). Similarly, OI brokers such as NineSigma or InnoCentive provide “solution finding” services to the users of their platforms, which are both solution seekers and international experts (Strategic Direction, 2008).

2.2.3 Quantitative studies

In their study of Chinese power equipment manufacturing firms, Wu and Chen (2010) emphasize the low level of external technology management capability, suggesting that Chinese firms should increase their investments into internal R&D and technology purchase to accumulate absorptive capacity and external technology management capabilities. Consistently, Wu and Zhou (2012) suggest that Chinese power equipment manufacturing firms switch from “market mode” (i.e. technology purchase) to “cooperative mode” (i.e. collaborative R&D activities) as their technological innovation capabilities grow.

A study within the Iranian power industry (Bagherinejad & Darjazini, 2013) describes the firms’ most popular approaches to OI, which include both selling and acquiring technologies and firms. The beneficial effects of OI were also discussed within the US Biofuel market (Weil, Sabhlok, & Cooney, 2014). Lam et al. (2012) show how firms are willing to cooperate with universities in order to develop environmental innovations.

The reviewed body of literature shows that the study of OI in the P&E sector is still in its early stages, mainly based on case studies that describe success stories, with few quantitative articles and even fewer theoretical studies. A theoretical framework describing the levers that influence the adoption of OI in the P&E is remarkably missing. This article aims to fill this gap in the literature.

2.3 Multiple cases study in the United Kingdom

One remarkable case of OI being supported by a public body is the “Innovate UK” (IUK) agency (Gov.uk, 2015). Its aim is to “*fund, support and connect innovative businesses to accelerate sustainable economic growth*” (Innovate UK, 2015d). IUK efforts are directed at identifying market and technology areas with the greatest potential for growth and funding projects to develop these strategic sectors. Noticeably, projects related to the P&E sector are the most frequently funded by the agency. IUK developed several tools to achieve its institutional goal:

- catapult centers: physical centers where UK businessmen, scientists, and engineers work side by side on late-stage research and development,
- collaborative R&D: co-funding of projects between firms and universities,
- innovation vouchers: grants of up to £5000 available to encourage firms to work with a new supplier and favor knowledge or technology transfer from it,
- _connect: an online business networking and OI portal,
- Knowledge Transfer Partnerships (KTP): a funding mechanism encouraging the partnership between a firm and a knowledge-based partner (Innovate UK, 2015a).

In this article, we specifically analyze the KTP tool due to the large availability of public information about the funded projects, including their background and their outcome. A KTP is a collaboration program between a knowledge-based partner (i.e. a research institution), a company partner and one or more associates (i.e. recently qualified persons such as graduates) (Innovate UK, 2015b). KTP initiatives aim to deliver significant improvement in business partners' profitability as a direct result of the partnership through enhanced quality and operations, increased sales and access to new markets (Innovate UK, 2015c). At the end of their KTP project, the three actors involved have to prepare a final report that describes KTP initiative supported the achievement of the project's innovation goals. As these reports are freely available on the KTP website, plenty of valuable information in terms of qualitative and quantitative data are available for the researchers. By examining these reports it is possible to understand the project inputs and outcome, assessing strengths and the weaknesses of the KTP program.

2.4 A holistic overview: Fuzzy Cognitive Map

Since the drivers of the OI adoption in the P&E sector mutually influence one another, it is ideal to describe them with an FCM. FCMs are "*fuzzy-graph structures for representing causal reasoning*" (Kosko, 1986). FCM is described by nodes (representing the elements of the analysis) linked by arrows (representing causal relationships). FCM has been used in literature to describe complex scenarios such as the identification of limitations to the development of wind power (Huang, Lo, & Lin, 2013) and information decision support systems for the planning of power plant harvesting renewable energy (Kyriakarakos, Patlitzianas, Damasiotis, & Papastefanakis, 2014).

In the FCM presented in section 3.2 each node represents a key driver related to the OI in the P&E sector. When two nodes are connected, it means that a cause-effect relationship exists between these elements. Each arrow's edge is associated to the mathematical sign plus or minus: positive edges represent "causal increase" while negative edges represent "causal decrease" (Kosko, 1986).

3 Results

3.1 KTP Case Studies

The next sections briefly present the key reason and benefits for firms to engage in the KTP R&D projects. Information was retrieved from (KTP Innovate UK, 2015). A synthesis of each of the reviewed KTP R&D projects with the salient information about OI is available in Appendix A.

In summary, the cross-case analysis of KTP case studies provides a number of relevant insights.

As expected, companies started this collaboration project for R&D reasons. However, the common feature of these projects is pursuing R&D outside the “established path”. In other words, a company selling product X or providing the service Y was not looking for an improved (e.g. more efficient) version of product X or a marginal improvement of service Y, but rather for a completely new product, market or service. The keywords linking the KTP projects are “discontinuity” with current R&D practices and “radical innovation”. Furthermore, innovation is not always related to a certain physical product, but often includes also new management systems or even a new marketing strategy. The innovation pursued from KTP range therefore from hard technical R&D to R&D related to marketing.

3.1.1 Key fact and statistics

Among all the KTP projects we selected those related to the P&E sector. Table 2 summarizes the characteristics of the seven projects identified. Firms involved in the projects are all small and medium enterprises (SMEs). In 5 out of 7 cases, firms have between 10 and 49 employees, and in 2 out of 7 cases they have between 50 and 249 employees.

TABLE 2 ABOUT HERE

Table 3 summarizes the main benefit generated by the KTP projects. Firms benefited from KTP projects in many ways, including the increase in their profits or sales, the improvement of their know-how, the foundation of spin-offs and the development of a new product. The universities involved in the projects obtained several benefits as well, experiencing an improvement in their know-how and the generation of new content for teaching and learning. Furthermore, three universities benefited from KTP by supporting Bachelor Dissertations, Master Dissertations, and Ph.D. collaborations. Finally, associates (i.e. the university students allocated to the companies) achieved the most remarkable advantages. Most of them improved their know-how, four of them earned a new National Vocational Qualification (NVQ) level, three became Ph.D. students developing projects in collaboration with the companies. In 6 out of 7 collaborations, the associates received a job offer from their collaborating firm.

TABLE 3 ABOUT HERE

3.1.2 Stakeholders perspective from the KTP cases

As clear from the cross-case analysis the stakeholders involved in the KTP benefit from it in a number of ways. The companies involved got access to the skills and knowledge available in British universities and academically trained students (the associates) focused on the project. This brought a novel and fresh approach towards the R&D in the benefiting companies. The associates were not involved for marginal, incremental improvement in existing products. Conversely, the associates worked in new ventures expanding the existing boundaries of R&D and business of the companies. Associates got a valuable experience corroborating their background. They were exposed to real business problems and had the opportunity to liaise with more experienced colleagues. As introduced before, most of those students obtained a job position at the end of the project, demonstrating that the collaboration had been fruitful for both the parties and created a real value. Other students, inspired by the R&D experience, came back to the academy to acquire further skills and foster R&D within a graduate scheme. The universities and academics leased with companies were exposed to contemporary and real life projects. KTP projects pushed academics to come out from the “ivory tower” and get in contact with local companies with concrete problems. A number of other spin-off benefits can be ascribed to KTP project such as the development of further mini-projects in the form of dissertations.

3.2 *Fuzzy Cognitive Map*

Figure 3 presents the FCM summarizing the key concepts related to OI in P&E firms. We identified 16 variables influencing the propensity of a firm to embrace the OI paradigm. As discussed before, the links are justified by specific P&E literature, generic OI literature, and the analysis of the KTP case studies. Among the variables, five plays a major role, both directly influencing the *OI in P&E firms* node, and acting as converging gateways for other variables: *Government involvement*, *Academia involvement*, *Customers and Suppliers involvement*, *Absorptive capacity*, and *Innovation novelty*.

FIGURE 3 ABOUT HERE

3.2.1 Government Involvement

Governments can encourage firms to adopt the OI paradigm through appropriate policies. For instance, Chesbrough (2006) emphasized how the Bayh-Dole Act encouraged the cooperation between universities and firms. Also in the P&E sector, several authors observed the role of the government in encouraging firms to collaborate to develop innovations related to cost effective and renewable energy sources (Hakkim & Heidrick, 2008; Stern, 2008). Furthermore, the KTP case studies presented in this article reinforce the idea that the government can drive, through legislation and funding assignment, the firms' openness.

In many cases, public funding initiatives are addressed by public authorities to encourage inter-organizational cooperation arrangements (Gallego, Rubalcaba, & Suárez, 2013), and therefore play a major role in enhancing OI in firms. Governments are often prone to reduce their funding of research activities in the absence of macroeconomic growth, in order to sooth their deficits. Conversely, in the P&E sector, the public expenditure in research is positively correlated with the Gross Domestic Product (Bointner, 2014). Public efforts in energy R&D are also dependent on the fossil primary energy availability (and consequently of its cost) and on the environmental constraints (i.e. pollution or other externalities) (Witte, 2009). The increasing pressure for an enhancement of firms' efficiency in an environmental perspective is a major force influencing policy-makers in the promotion of OI programs in the P&E sector (Ramirez-Portilla, Cagno, & Trianni, 2014a; Ramirez-Portilla, Cagno, Trianni, & Brown, 2013).

3.2.2 Academic Involvement

The involvement of Academia is a major driver of OI, as universities can enhance firms' capabilities to ideate inventions and can help them to test their prototypes in lab facilities (Tolvanen et al., 2011), universities can add cutting edge technology to the firms' products (Pinnekamp, 2007) and support them in their participation in innovation funding programs (as seen in the case of KTP). In another point of view, universities can also acquire knowledge or technologies from firms (Jin-Hyo et al., 2010), for example when firms are specialized in certain specific niches or own sophisticated technological instruments that complement those owned by a university.

Several authors suggested that larger enterprises are more likely to collaborate with universities than smaller ones (Cohen, Nelson, & Walsh, 2002; Henttonen & Hurmelinna-Laukkanen, 2014; Lam et al., 2012; Laursen & Salter, 2004). In fact, large firms' comparatively higher level of research competence and investment capital, as well as their stronger networking capability, make them more keen to collaborate with universities (Lam et al., 2012). Therefore, we positively correlated the *Academia involvement* node with the node *Firm size*.

The novelty of innovation is a key driver for the involvement of academia as well. Firms in the P&E sector prefer drawing their profits from incremental innovations rather than from radical innovations (Witte, 2009). Conversely, within the academia, scholars often are more inclined to point out radical innovations, which are more likely to be appreciated in the scientific community. When firms need to address significant challenges in the deployment of novel technologies academic institutions support them, improving their success chances (González et al., 2012; Pellegrini et al., 2012; Sahir et al., 2012; Srikanth, 2011). Often firms cooperate with academic spin-offs that were incorporated to develop and bring to the market breakthrough technologies ideated earlier in the academia (Hess & Siegwart, 2014).

Public policies can dramatically enhance the academic capabilities to sustain OI in the P&E sector, as shown in (Lam et al., 2012) and by the KTP case studies. Indeed, public policies help firms to find the right university partners (Lam et al., 2012). Therefore we pose that the *Academia involvement* node is positively influenced by *Government involvement*.

As shown by the KTP case studies, when firms need human resources with academic skills, they are prompted to collaborate with universities. Environmental constraints are another promoter of academic involvement. Environmental constraints increase over time and, in some situations, incremental R&D could suffice to respect them. New ideas and paradigms are required. Academics and students can provide a refreshing outside view consistent with the state of the art. New market opportunities come with a lot of unknowns that firms can struggle to face. Knowledge and tools to support the venture and identify the key risks are often owned by the academia. For instance academics and students have access, through the university website, to a body of literature, data and software usually not available for companies, particularly SME.

Finally, the openness of a firm itself, or eventually the commitment of its management to embrace the OI paradigm are a clear stimulus for academia to collaborate with it (Costello, Rochford, & Donnellan, 2013).

3.2.3 Customers and Suppliers Involvement

Firms can benefit from active interactions with their customers, satisfying their requirements and expectations (Jin-Hyo et al., 2010). Such interactions may be systemized and strengthen through "call for ideas" and contests. In turn, we pose that *Customers and suppliers involvement* node is positively influenced by *OI in P&E firms*, since the involvement of the customers depends on the firm's willingness and capability to involve them, i.e. on the firm openness (Gassmann, 2006). The General Electric Ecoimagination case (Chesbrough, 2012) shows how a firm that becomes aware of the vast innovation activity underlying outside its organizational boundaries is also incentivized to start initiatives to identify and develop external ideas that might strengthen its own business.

3.2.4 Absorptive capacity

The *absorptive capacity* is influenced by *Resistance to external ideas* (i.e. the so-called Not Invented Here syndrome)*, Internal R&D* and *Network Capabilities* (Cohen & Levinthal, 1990). The absorptive capacity is considered an important enabler of OI (Greco, Grimaldi, et al., 2015; Henttonen & Hurmelinna-Laukkanen, 2014) and a success factor of alliances (Hurmelinna-Laukkanen et al., 2012). In this perspective, P&E firms have been encouraged to invest in internal R&D to accumulate absorptive capacity (Wu & Chen, 2010). As suggested by Wu and Zhou (2012) the growth of technological innovation capabilities, which is assessed in terms of R&D inputs, can make firms switching to a cooperation mode from a market model. We argue that this positive effect on firms' openness is rather indirect, encompassing a higher absorptive capacity.

In turn, a firm *Networking capabilities,* as well as *Internal R&D* are usually strongly influenced by its size. With respect to an SME, a large firm has more resources to invest in research and a wider network of partners and stakeholders that can be involved in OI activities (Henttonen & Hurmelinna-Laukkanen, 2014; Lee, Park, Yoon, & Park, 2010; Locatelli, Mancini, & Romano, 2014; Rocha, 1999; van de Vrande, de Jong, Vanhaverbeke, & de Rochemont, 2009).

3.2.5 Innovation novelty

The node *Innovation novelty* describes the attitude of a firm to develop novel products rather than to improve existing ones. In this perspective, one of the most relevant causes of market failure (Arrow, 1962; Bointner, 2014; Witte, 2009) is the nature of the learning process. In fact, a radically new technology takes very long to become profitable, even several decades in the P&E sector, because of the learning curve (GIF/EMWG, 2007). Radically new technologies may not become cost effective until significant investments have been made and experience developed. Significant learning effects may reduce the incentive to invest in innovation if companies wait until the innovator has already proven a market for a new cost-effective technology (Stern, 2008). In addition, the P&E sector operates in a strictly regulated context, making P&E firms quite risk averse (Klitkou & Godoe, 2013;

Rennings, Markewitz, & Vögele, 2010). It is hard to find niche markets for early adopters in P&E sector, so P&E companies are stuck with learning costs (Witte, 2009). Together, these factors could push energy generation technologies into a "valley of death" where potentially profitable innovations fail to come to the market (Arrow, 1962; Witte, 2009). For these reasons, firms in the P&E sector usually prefer incremental innovations with fewer risks and development costs. Nevertheless, firms may share the inherent risk of the innovation process with their OI partners in order to develop radical innovations (Nieto & Santamarìa, 2007). OI practices like consortiums and collaborations can bring radical changes in their markets, as happened in the Canadian Oil sand market (Hakkim & Heidrick, 2008) and in the USA biofuel market (Weil et al., 2014).

OI practices seem to be useful to share the costs and risks of innovation (Papadopoulos, Stamati, Nikolaidou, & Anagnostopoulos, 2013), especially when the firm wants to develop novel products. In this perspective, we argue that firms involved in radically innovative projects will more likely resort to OI than firms pursuing incremental innovations. This justifies the positive link from the node *innovation novelty* to the node *OI in P&E firms*.

Noticeably, firms based in developing countries tend to imitate rather than to conduct research on novelties (Bo & Yang, 2012; Mathews, 2002). Thus, in underdeveloped countries, OI practices may not allow the firms to pursue radical innovation and then we hypothesize a positive link from *Country development* to *Innovation novelty*.

3.2.6 Other variables

Some additional variables play a relevant role in influencing *OI in P&E firms*. As suggested in the literature (Bo & Yang, 2012; Greco, Cricelli, & Grimaldi, 2015), firms based in developed countries are more likely to be open than firms based in underdeveloped ones. Concerns related to the costs of energy produced from fossil sources, both in economic and in corporate image terms, can directly prompt firms to collaborate with external subjects to improve their energy efficiency and to balance their energy mix towards renewable sources, as observed in the case of P&G (Meller, 2011; Witte, 2009). Finally, Carbone et al. (2012) suggest that in the case of economic downturn companies increasingly search more efficient and creative business processes such as those encompassed in the OI paradigm, especially when put into relation with a Web 2.0 approach. Similarly, Papadopoulos et al. (2013) emphasize that when an economic crisis is incumbent or present, the OI tools (i.e. open source program used to improve the research, crowd searching activities, licensing, etc.) can foster the innovation even if there is a reduced budget for the R&D.

4 Conclusion and Policy Implications

The P&E sector faces a number of R&D challenges all over its domain. These challenges include the development of more cost-effective photovoltaic plants, energy storage technologies, decommissioning and decontamination of nuclear facilities etc. Consequently, R&D investments in the P&E sector are massive. Such investments are the result of contingent factors (e.g. the availability of certain technologies), policy decisions (e.g. the introduction of subsidies) or even market trends (e.g. the cost of a certain fuel). Quite astonishingly, despite this interest in R&D, few scholars investigated how P&E firms innovate, how they can improve their approach and which policies can foster their efforts.

This article provides an analysis of the phenomenon taking the lead from the OI paradigm, according to which firms should collaborate with external subjects to enhance the effectiveness and efficiency of internal R&D investments. On the one hand, P&E firms attempt to identify solutions in order to accelerate the future changes in the energy system. On the other hand, the nature of the energy market and the nature of the learning curve request the intervention of policy makers in order to make the innovations feasible. In this perspective, enhancing the OI paradigm adoption may concur in increasing the firms' R&D productivity and have substantial social spillover benefits. P&E firms that open their innovation process can share costs and risks, making the technological breakthroughs more sustainable. This might encourage P&E firms to attempt research programs aimed to develop radical innovations, which are often very expensive and not always attractive to firms operating in the P&E

sector. Indeed, in this sector, while research institutions are specifically interested in collaborating with firms to develop radical, breakthrough inventions, firms are apparently more lured by researches aimed to develop incremental, low-risk innovation.

The findings of this study have several important policy implications related to the OI paradigm that would maximize the benefits and enhance the investments in R&D. The evidence from this study suggests the following key policy recommendations:

1. Policy makers need to set-up mechanisms fostering the collaboration between industry and academia. As observed for KTP, even in a time of scarce resources, policy makers may play a central role by allocating their limited budget for OI to relatively small projects (less than 100.000€ in KTP) that can originate long-term collaborations. This article showed how cleverly financed projects such as the KTP enhance both the knowledge flow from research institutions to companies and allow the associates to find qualified jobs, reinforcing the firms' specialized human capital. Providing funds for multi-partner research projects might consider involving not only firms and research institutions, but also private citizens with certain competencies and ambitions.
2. Academia is a major player in an OI perspective. Its interaction with the P&E sector has been incentivized by governments and international institutions (such as the European Commission) in various ways. Universities are targets of many different public subsidies for joint collaborations, and in several countries the processes to start-up academic spin-offs and to manage academic intellectual property have been remarkably simplified. Finally, in several countries, the economic impact of a research institution is a fundamental driver of national rankings. Nevertheless, there is still some mistrust in academia-industry relationships. Favoring frequent and fecund interactions between universities and firms might crack the cultural barriers that still exist in many countries between such pivotal players of innovation. An enhancement of the firms' absorptive capacity will improve their capability to purposely interact with academics. In this perspective,

policy makers can favor investments on internal R&D (for example, through tax credits) and on life-long learning initiatives of firms' workers and managers.

3. The FCM shows how innovation novelty plays a pivotal role in enhancing purposive collaborations. In this perspective, policy makers should preferably subsidize the most innovative projects, instead of marginal/incremental R&D projects. A policy priority should be planning for the long-term innovation needed and support this by setting the background (laws, incentives etc.) to incentivize the OI paradigm adoption in the P&E sector.
4. Policy makers need to keep an open mind about the contribution of the OI paradigm in the P&E sector. OI should not only be considered a mean to design and develop new technologies or "hard science". In fact, OI can be applied even in the domain of industrial engineering (e.g. developing practices fostering the energy efficiency in SME) or even in the social science domain (e.g. marketing to reduce the consumption of energy for the household).

This article sets the background and paves the way for future research on OI in the P&E sector. Firstly, firms need a set of criteria and guidelines to establish the amount of resources to be allocated to OI. Secondly, further studies should shed light on the most rewarding OI actions for firms operating in the P&E sector. For instance, they should clarify whether it is better to pursue OI with few, well-established actors (e.g. few projects with leading universities) or split the budget within many stakeholders (e.g. many projects involving regional universities). In particular, quantitative studies exploring costs and benefits of OI in the P&E sector are needed. Finally, as energy policy makers should rethink their agenda to include mechanisms fostering OI, further research should be devoted to understanding how to set up grant applications to foster OI in the P&E sector.

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Appendix A

Solarcentury Holdings Ltd – KR: NEW PRODUCT AND NEW SERVICES

Solarcentury Holdings Ltd operates in the solar-energy field, delivering large-scale renewable energy solutions for electricity and heating water producer. The KTP goal was to launch a new product development team and find opportunities during the design of photovoltaic installations, which could be translated into new products and services for UK solar market.

Inditherm P – KR: NEW PRODUCT TO GET IN A NEW MARKET

The company is a provider solutions for heating problems using a unique carbon-based polymer technology. The company had developed the technology into industrial and medical markets but wanted to exploit it within the construction industry, which it recognized as a potentially major market. The research consisted in the development of a system to enable in-situ concrete curing during the winter periods and the identification of benefits and potential markets within the construction sector. A new business segment was established

Aberdeen Harbour Board – KR: NEW MANAGEMENT SYSTEM FOR INCREASING CUSTOMERS

The Board is responsible for one of the UK's Trust Ports. It aimed to bring services to the Northern Isles, as well as to support the offshore oil and gas industry. With environmental sustainability being at the forefront of many business operations, the Board realized that an environmental management system would allow them to improve environmental performance. This allowed attracting new customers, as well as retaining existing ones.

B9 Energy O&M Ltd - KR: DEVELOP A NEW METHOD FOR A NEW MARKET

B9 Energy O&M Ltd focuses on clean energy technologies. The company aimed to expand its activity in the market of energy generated from waste, and needed to build its knowledge and expertise. This KTP developed a pre-treatment methods to optimise energy production from organic materials, using anaerobic digestion technology to develop energy from waste. A new venture has been formed to take forward renewable energy from organic waste projects, including the commercialisation of the enhanced AD system developed under the KTP project.

CSMA Ltd – KR: DEVELOP OF A NEW SOFTWARE FOR ASSESSING ENVIRONMENTAL IMPACT

CSMA Consultants Ltd is an earth resources consultancy company specialized in mining, minerals and renewable energy issues, particularly wind power, waste to energy and biofuels. The aim of the KTP was to develop an optimal computerized methodology for the environmental impact assessment of wind farms or renewable energy projects, using available and innovative software. At the end of the KTP project, CSMA Consultants Ltd obtained an increased knowledge of UK and other European planning legislation and planning systems, the company was also able to implement a new approach and to define a methodology for the production of environmental statements.

Sigen Ltd – KR: HARD ENGINEERING R&D INNOVATION

Sigen Ltd designs small-scale energy systems, using hydrogen fuel cells and small hydrogen production systems. The company offers consultancy to design, test and install according to specific customer needs. It integrates renewable energy and hydrogen systems to decrease fossil hydrocarbon energy dependence. Sigen was asked by Unst Renewable Energy Project to design, install and test a small demonstrator unit. The project involved using two wind turbines to provide power to a small industrial building via the production of hydrogen and the use of surplus hydrogen for other power projects.

Steel Construction Institute – KR: DEVELOPMENT OF A SOFTWARE FOR SAFETY AUDITS

The Steel Construction Institute undertakes research and develops technology aimed to support the use of steel in construction. The aim of the KTP was to develop a software tool for auditing the performance of safety critical elements on offshore Oil & Gas installations. The KTP project allowed the company to access the university's expertise about structural mechanics, dynamics of structures, fatigue, corrosion fatigue, fracture, safety risk and reliability engineering. The project delivered an audit tool that will be licensed and/or used to offer consultancy services, thereby generating revenue for the institute.

West Coast Energy Ltd – KE: DEVELOPMENT OF A MARKETING TOOL

West Coast Energy Ltd is an independent wind energy developer based in North Wales. The company is specialized in the identification, design, planning and development of wind energy projects. The company wanted to use this information to adjust its business plan, identify emerging market opportunities and grow. The KTP project successfully provided knowledge about present and potential markets, and also delivered the quality market intelligence necessary to make appropriate strategic decisions. New capabilities have been transferred to the company, including the ability to hold focus groups, maintain and refine websites and produce e-newsletters. The project also brought about the creation of two new posts to manage key marketing functions.