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Solar energy technologies and open innovation: A study based on bibliometric and social network analysis

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ABSTRACT

This paper aims to identify the development of solar energy technologies through open innovation. Manuscripts about solar energy and open innovation published between the years 2000 and 2014 in journals indexed by Web of Science Core Collection were used to create a database and terms related to solar energy and open innovation were sought in papers title, summary and keywords. By using words “cooperation” and “collaboration” as a proxy to map open innovation, it was found that this approach exist widely for solar energy researches and most important publications was developed collaboratively. Social network analysis methodology was used to identified clusters of local, national and international partnerships, which prove that researches cooperation to solar energy technological development is true. International cooperation is prevalent in countries like the Netherlands, United Kingdom, Spain and Germany. National partnership occurs in Japan, United States, France, Italy and South Korea. China has predominant local cooperation profile, but it will be major international collaborative actor in solar energy researches next years. Also, a set of recommendations based on findings was provided to construct a better environment for cooperation and to improve solar energy researches.

1. Introduction

The global challenge surrounding the minimization of climate changes has increasingly aroused the interest in mechanisms that foster development and in new technologies that reduce the environmental impact of the current economic development of several countries. Green technologies are crucial for sustainable development as well as for the creation of new business opportunities. The green technology concept has gained momentum in academic studies and has sought to shed further light upon the key dynamics that underlies its nature and to urge policymakers and companies to support its development (Albino et al., 2014).

One of the green technologies with highest potential is that of solar energy (SE) as it is a renewable and non-polluting resource. SE techniques consist of the use of concentrated solar power (CSP) and photovoltaic (PV) systems. CSP usually collects solar radiation and uses water or other means in order to generate power whereas the PV technology converts sunlight directly to electricity, depending on the photoelectric effect (Dong et al., 2012).

According to the International Energy Agency (IEA, 2014a, 2014b), the development of SE technologies can bring huge benefits in the long term. Driven by technological breakthroughs, solar thermal energy (STE) and PV systems compete with the generation of electricity from oil sources in some countries. The highly renewable energy source scenarios have shown that the production of electricity from PV and STE, and PV and STE together, will have could supply up to 25% of global electricity by 2050 (IEA, 2014a, 2014b). In order to take good advantage of this prospect of wealth generation through the development of clean energy, companies will have to invest in research, development, and innovation (R & D & I). Along this line, Dong et al. (2012) demonstrate a linear growth in publications on SE between 1991 and 2010, revealing a growing interest in this topic.

Owing to the increasing tendency of collaborations for innovation beyond organizational frontiers, the strategic importance of seeking potential partners for technology development has risen with the advent of open innovation (OI). Different-sized companies have sought OI based initiatives to exploit all their innovation potential, as pointed out by Chesbrough (2003b), when he assessed large enterprises such as Procter & Gamble, and also for small and medium-sized enterprises (SME) as studied by Van de Vrande et al. (2009). For Abulrub and Lee (2012), the interest in OI has increased both in the business and academic environments.

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In recent years, investigations into OI, with a broad array of scopes, have abounded, indicating that organizations have welcomed this effort (Gassmann, 2006). According to Huizingh (2011), studies on OI involve different sectors, such as electronics, food, financial services, cars, and biotechnology. OI has become the most appropriate innovation management model in the globalized world, characterized by technology intensity, technology fusion, new business models, and knowledge leveraging (Gassmann, 2006).

Based on the technological efforts channeled by organizations into the development of clean energy technologies, especially SE, and on the likelihood of companies adopting the OI model, the present paper conducts a bibliometric analysis to assess scientific publications on these two topics, putting forward the hypothesis that it is possible to identify signs of the OI management model in publications on the development of SE technologies. This hypothesis allows evaluating whether the undertaking of studies on SE production takes place within a context of cooperation and development between R & D and external actors, as proposed in the OI model.

2. Open Innovation (OI)

The concept of innovation is comprehensive, since it is associated with everything that differentiates and adds value to a business. Schumpeter (1984) underscored that innovation means "new combinations," a paramount phenomenon in economic development. A more recent definition is that of the Oslo Manual (OECD, 2005, p. 32), according to which: "Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes."

Thus, in order for companies to achieve these different kinds of innovations, Chesbrough (2003a) proposes an innovation management model that maximizes profit through the active use of both external and internal ideas and knowledge, the so-called OI. This approach entails a different way of thinking, and its applications are countless, ranging from mere collaborative exchange to activities that involve other companies, customers, suppliers, scientific and technological institutes, in addition to the import and/or export of ideas (Porto and Costa, 2013).

For Huizingh (2011), after the works by Chesbrough (2003a) published more than 10 years ago, it is clear that the roots of OI transcend history. One can say that the use of external contributions to improve internal innovation processes is not new, and neither is the acquisition of external technologies to improve innovation processes. OI is often contrasted with closed innovation, wherein companies create their own ideas of innovation, and then develop, construct, commercialize, distribute, self-finance, and support themselves, employing a proprietary technology model. In OI, it is assumed that the best technological solution will not always be developed internally without the participation of any other kind of organization, but that the internalization of external technologies will significantly contribute to the business model of a company, which should be able to monitor the external environment and allow for knowledge inflow that complements its main competences (Chesbrough, 2003a).

The basic OI principle consists in opening the whole innovation process, allowing for unused ideas and innovations and assimilation of external technologies and opportunities, whose process can be mediated by another organization so as to expedite and/or enable knowledge transfer. Therefore, it is possible to say that OI is a broad concept that involves different domains, particularly the flow of knowledge between a company and external actors. This flow shows the movements of purposive outflows and inflows of knowledge expected to accelerate innovation processes and to improve the benefits of innovative efforts. Purposive outflows of knowledge, also known as technology exploitation or inside-out process, imply that existing technological resources seep out beyond the company's boundaries. Conversely, purposive inflow of knowledge, also called technology exploration or outside-in process, refers to capturing and taking good advantage of external sources of knowledge in order to improve current technological developments. In a fully open environment, companies combine both inbound and outbound technology transfer in order to attach a value as large as possible to their technological capabilities or other competences (Chesbrough et al., 2006; Chesbrough and Crowther, 2006; Lichtenthaler, 2008).

In general, an OI definition in line with present study can be understood as a model of innovation management which different organizations try to collaborate, cooperate and share knowledge among themselves to complement their internal innovation efforts and aiming for technological improvements to be translated into business advantages (Chesbrough, 2003a; Chesbrough et al., 2006; Lichtenthaler, 2011; Hutter et al., 2011). In addition, OI address two dimensions of technology exchange: first, inside-out process (outbound) which is the process through which firms transfer their technologies to external organizations for commercial exploitation, e.g., out-licensing, new venture spin-out, sale of innovation projects, joint ventures (Chesbrough, 2006; Van de Vrande et al., 2009; Bianchi et al., 2010 p 414). Second, OI dimension is outside-in process (inbound) which is the practice of leveraging the technologies of others by accessing their technical and scientific knowledge, e.g., in-licensing, minority equity investments, acquisitions, R & D contracts" (Chesbrough and Crowther, 2006; Gassmann, 2006; Chesbrough, 2011 p 88).

OI and cooperation were also investigated by Wang et al. (2012), who found that OI influences the National Innovation System (NIS) by strengthening its importance, improving its efficacy, and diversifying its innovation networks. In another paper, Su and Lee (2012) mapped out the OI research framework by quantitatively assessing studies on this topic published in the *Web of Science* database and observed important components, in addition to showcasing the OI global research framework. Their work demonstrated an alternative to contemplate and evaluate the structure of the research community and to estimate possible applications to studies on OI. Hence, the present paper contributes to the debate on OI by describing the impact of SE technology development.

3. Solar energy (SE)

The development of SE technologies from the 1860s (Kalogirou, 2004), in the form of CSP, was stimulated by the prediction that conventional energy sources would soon be depleted. According to Dong et al. (2012), in the early 20th century, the development of SE technology stalled in view of the higher availability of conventional energy supplied by thermoelectric and hydroelectric power plants and by petroleum. Commercial CSP centers developed considerably in the 1970s when the oil embargo and the energy crisis set in.

According to the IEA (2014), between 1999 and 2013, the gross production of electricity based on SE technologies grew 106 times, going from 1050 GW h in 1999 to 112,150 GW h in 2013. Of this total, 95% are based on PV technologies and 78% of the world production of SE is controlled by Germany, Italy, Spain, United States, and Japan (Fig. 1).

Garg and Sharma (1991) analyzed the publication of articles between 1970 and 1984, using the terms *"solar cells," "solar energy," "solar power plants,"* and *"solar radiation measurement"* and observed an impressive growth in the volume of scientific publications after the energy crisis. Fig. 2 shows the global growth in SE production, underscoring the adoption of PV technology after 2010 due to a massive reduction in costs and to the distributed generation model. PV and STE, together, could be the world's largest source of electricity by 2050, (IEA, 2014a, 2014b).

An interesting fact described in the report of the 100 most innovative global companies (Reuters, 2015) concerns Oil & Gas companies that stood out as the ones that most gained positions in