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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

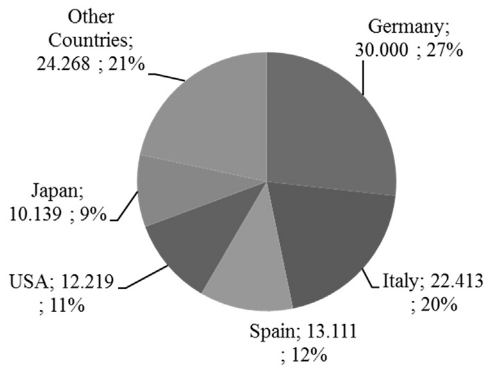

Fig. 1. Gross generation of electricity from SE in 2013. Source: Adapted from IEA - International Energy Agency. IEA Electricity Information Statistics - OECD - Electricity and heat generation (IEA, 2015).

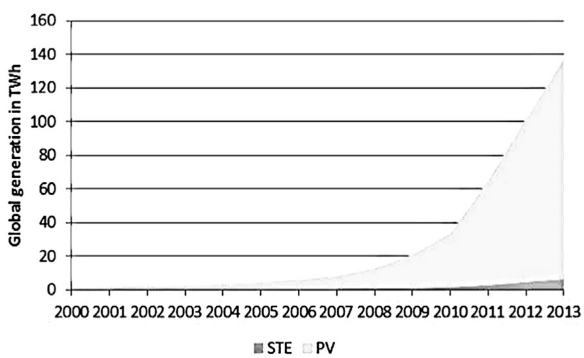

Fig. 2. Evolutionary behavior of SE production (STE + PV). Source: IEA (2014).

the innovation ranking. This increase is influenced by the expansion in conventional oil-based research for new areas of innovation related to alternative energy sources. The emergence of global innovative leaders who defend new energy sources for our planet has also been observed. The development of technologies such as SE has been a priority for innovative companies and pioneering research institutes. This way, the use of OI is expected to contribute to technological development processes.

By conducting a bibliometric study, Dong et al. (2012) assessed the situation and tendencies of SE research between 1991 and 2010 in order to help researchers have an overview of global SE research and predict the dynamics of investigation.

Growing energy efficiency literature between 1991 and 2010 was examined using bibliometric techniques and "energy efficiency" or "energy efficiencies" as search phrases (Du et al., 2013). These authors indicated top most active subject categories of energy efficiency: "energy and fuels", "environmental sciences", and "electrical and electronic engineering" and presented additional conclusion about the most important journal and the most highly cited article. Belter and Seidel (2013) analyzed climate engineering research using bibliometric techniques but they focused on several climate aspects and didn't explore technologies and trends of solar energy. Du et al. (2014) used bibliometric method to examine the characteristics of the solar energy literature from 1992 to 2011. These authors just used terms "solar energy" or "solar energies" and it can have limited number of publication that exist about this area.

Wei et al. (2015) applied the bibliometric method on climate policy modeling and they present some statistic about most productive authors, institutes and citations and major important research topics in climate area. Specifically, about solar technologies, this topic wasn't pointed as a main subject in this work. Using general statistics and hotspots based on bibliometric method, Yu et al. (2016) analyze the scientific publications that contain terms "low carbon energy technology" and "investment" and conclude that the main application of low-carbon energy technologies is in the electricity sector.

However, none of studies above have investigated aspects such as innovation management model adopted by companies to keep up with SE technology development. Once it is assumed that OI is a tool that optimizes the development of this sort of technology, it is possible to check for the simultaneous presence of OI in studies focused on SE development.

4. Methodology

The analysis of citations derives from bibliometrics and originates from the field of computer science. It has been widely applied to scientific progress and proposes paradigm shifts as it measures research productivity and analyzes the citations for a given topic (Moed, 2006). For Schneider and Borlund (2004), an analysis of research studies by bibliometric methods allows understanding and assessing what has been done and what has to be investigated.

In recent years, bibliometric studies have become an accurate and presumably objective method for assessing the contribution of an article to advancement of knowledge (Yi and Xi, 2008). In addition, the *Science Citation Index* (SCI) from *Web of Science* (WoS) is the most widely accepted and frequently used database for the analysis of scientific publications (Braun et al., 2000). According to Narin et al. (1994), the basic principle of bibliometric analysis is the quantification of scientific publications by means of technical performance parameters for determination of productivity. In this paper, scientific papers were selected from the *Web of Science Core Collection* database. The other databases available from *Web of Science* had few publications on SE and OI and were therefore discarded, without any interference with the general outcome of this study.

The search in Web of Science was made using keywords (search terms) commonly used to refer to SE and OI technologies. The search was restricted to articles published between 2000 and 2014. Basically, the aim was to obtain documents that included terms associated with SE and OI. It is important to highlight that the Boolean "AND" was used in order to verify the simultaneous occurrence of the terms SE and OI. Web of Science searches the title of the manuscript, its abstract, keywords, author, and Keywords Plus as the search option when the field "Subject" is checked.

Word or phrases frequency are a very usual way to analyze contents in different types of documents. Choosing correct expressions and words that represent the best semantic about an area is crucial to quantify and analyze technology trends. According to the previous publications (Belter and Seidel, 2013; Du et al., 2013; Du et al., 2014; Yu et al., 2016), we use bibliometric techniques and choose some specific terms to develop our analysis. For SE, the field "Subject" should have as search results articles with at least one of the following terms: "solar energ*", "solar power*", "solar radiation*", "solar generation*", "solar cell*", "solar therma*", "solar PV", and "photovolt*". Some of them were also used by Dong et al. (2012) in a more recent bibliometric study on SE. The special character "*" was used at the end of some terms to identify variations, thereby broadening the search.

Concomitantly, to include the term OI, the field "Subject" should be able to search for articles with at least one of the following keywords: "open innovation," "user innovation," "cumulative innovation," "know-how trading," "mass innovation," "distributed innovation," "innovative cooperation," and "collaborative innovation." The use of these search terms follows the recommendations made by Rahman and Ramos (2010), who indicate a close relationship of the term "open innovation" with the terms listed above. However, the search using the explicit terms that refer to OI together with the terms that refer to SE did not detect any document.

Based on other terms recurrently referred to in articles on OI (Chesbrough, 2003a, 2003b; Chesbrough and Crowther, 2006; Chesbrough et al., 2006), a new search was performed by combining the terms about SE mentioned earlier with new terms whose OI meaning is implied: "technolog* insourc*", "technolog* acquisit*", "technolog* commercializ*", "technolog* transfer*", "collaboration", "cooperation*", "inside-out", "outside-in", "*licencing*", "R & D", "*flows of knowledge", "technolog* spin-off", "internal technolog*", "external technolog*", and "crowdsourc*". The special character "*" was used again to allow for variations in the search terms related to SE and OI simultaneously, selecting only articles published between 2000 and 2014 and included in the *Web of Science* database. It is important to point out that some of previous mentioned terms, such as "R & D" and "technolo* commercializ*", do not refer exclusively to OI but are terms commonly cited in the literature related to OI. One can imagine a vies, but this will be better explained further through new refinement where terms will be further narrowed, papers analyzed in more detail and associate with OI.

In addition, Social Network Analysis (SNA), which allows identifying the close relationship between organizations (universities, research centers, or companies) in which research into SE was developed, was used. This means that the actors may be recognized as hubs in a cooperation network or as bridges between the different subnetworks (Newman, 2010). For the construction of networks, data such as title, authors, and address (institution and country) of the authors were exported and treated with Microsoft Excel resources until co-authorship data could be obtained.

Some previous works were published (Belter and Seidel, 2013; Du et al., 2014; Fahimnia et al., 2015) using SNA to present a graphical view and relation between actors related to climate and green technologies. For this paper, Gephi version 0.8.2 software was used as a tool for construction, visualization, and analysis of SE and OI networks (Bastian et al., 2009). Initially, a bipartite network was built, in which the nodes are the organizations that connected with each other through nodes that represent the titles of papers. Thereafter, the nodes with the names of the articles were turned into edges that linked the organizations, making up the final network. Modularity, degree, weighted average degree, and PageRank (Page et al., 1999) were SNA statistics that were used in order to make the necessary analyses and conclusions (Jackson, 2010).

5. Results

The following subsections introduce and discuss the results obtained in this study. Such results are present in the analyses of publications/citations, search terms (keywords) and also in the assessment of the major sources of publication/citation and of main authors. A detailed analysis of the major publications on the topic is carried out and co-authorship networks are built for the organizations that have developed research into OI and SE.

5.1. Analysis of publications and citations

The search criteria used in this study yielded a total of 739 articles published between 2000 and 2014. The number of publications remained unchanged between 2000 and 2004, around 25 publications/year. From 2005 to 2009, the average number of publications per year increased to 32 and between 2010 and 2014 it tripled, corresponding to 91 publications per year (Fig. 3). Note that publications on the topics show a mild exponential increase, quite close to a linear increase.

Looking at the amount of citations in these 739 articles, there were 12,485 citations distributed along the study period, with an average of 16.89 citations per published article. The number of citations increases gradually every year with the amount of publications per year. However, there is a tendency towards a growth in the number of citations (Fig. 3).

Fig. 4 shows the distribution of publications and their citations grouped into 5-year periods and confirms the increase in the amount of publications and citations. Moreover, the average number of citations per article has increased in each 5-year period.

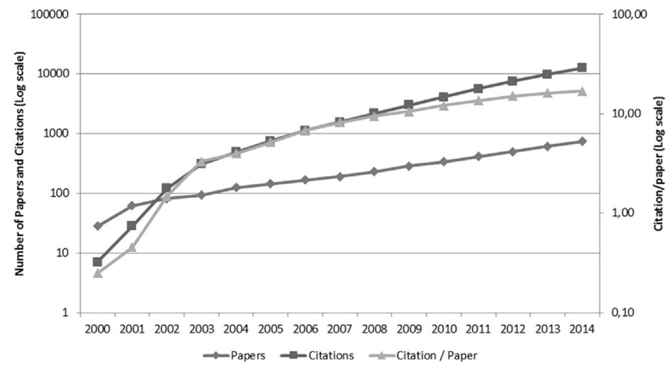

Fig. 3. Cumulative publications and citations between 2000 and 2014.

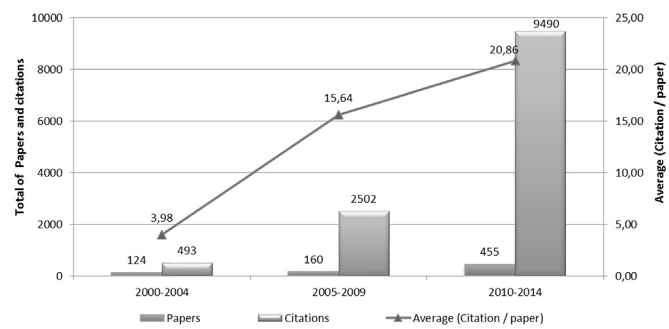

Fig. 4. Cumulative publications and citations per period of 5 years.

5.2. Analysis of keywords used in the search

The analysis of keywords used in the search of articles on SE and OI (Fig. 5) allowed identifying the frequency of each term in the documents, more specifically in the abstracts of each article. Note that the keywords "cooperat*", *"solar cell*", "photovol*", "R & D", "transfer*", "collaborat*",* and *"solar energ*"* are much more frequent than the other terms. These seven terms total 89.7% of the frequencies obtained. In addition, there are some keywords that were not found, not even once, in the abstracts of the articles, such as "licenc*",*"solar generation", "insourc*", "outside-in", "*flows of knowledge", "spin-off", "internal technolog*",* and "crowdsourc*". Of these, except for the keyword "solar generation" all are associated with OI. Therefore, the absence of terms that ought to make explicit the use of OI in the development of SE demonstrates that the practices analyzed in these articles do not directly indicate specific *outside-in* or *inside-out* processes that are typical of OI models (Lichtenthaler, 2008). Nonetheless, the presence of the terms "*cooperation*" and "*collaboration*" are conducive to a joint development process in documents about SE. This way, although indirectly, it is possible to affirm that there exists an OI model in which the investigated object is developed in a joint, shared, and collaborative fashion (Porto and Costa, 2013).

Fig. 6 shows the frequency of the terms "cooperat*",*"solar cell*", "photovolt*", "R & D", "transfer*", "collaborat*"* and *"solar energ*".* Note that the frequency of words has a similar behavior up to 2006. From then on, all these terms increase their frequency year after year, with particular emphasis on the keyword "cooperat*" whose frequency is way above that of the other terms.

5.3. Analysis of the major sources of publication and citation

This study identified 358 different sources of publication for the terms associated with SE and OI. The 15 main sources of citation and

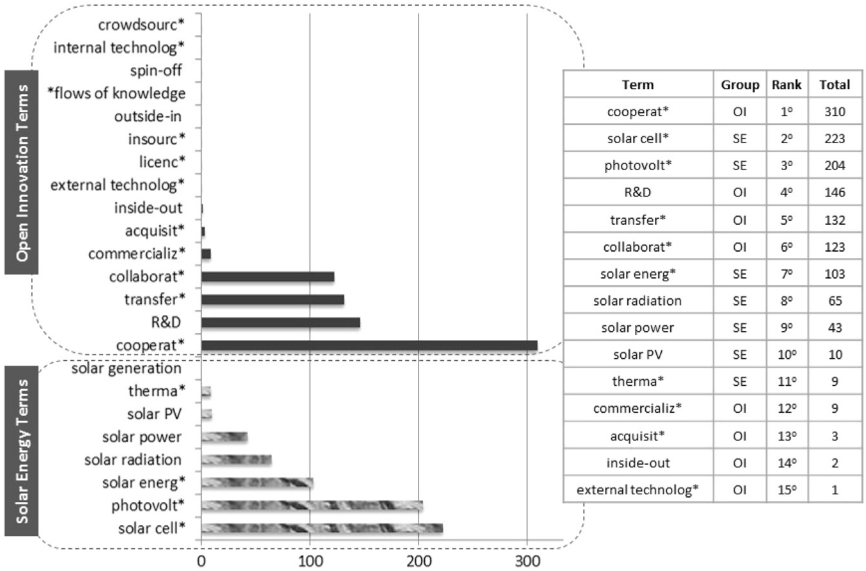

Fig. 5. Frequency of search terms in all publications between 2000 and 2014.

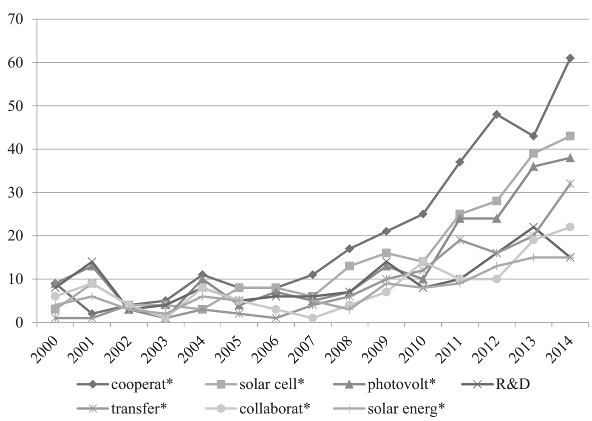

Fig. 6. Frequency of major search terms.

publication (Table 1) are grouped in decreasing order from the most widely cited to the least widely cited author. Bear in mind that the citations refer to the articles of these sources cited in other articles. When an article is very relevant - a single article with many citations, the articles in that journal are few but largely cited, meaning that the articles do make a difference in their field of knowledge. When a journal includes several articles, but the number of citations in each one is not large, the contribution of these articles is not so relevant.

Note that the 15 sources of publication account for 22.9% of the total number of publications and 45.1% of the citations associated with the investigated topics. The five most widely cited journals were: a) *Solar Energy, b) Journal of Geophysical Research-Atmospheres, c) Advanced Functional Materials, d) Journal of The American Chemical Society,* and e) Applied Physics Letters. The columns "Rank Citations" and "Rank Publications" in Table 1 show the classification of the journals based on the amount of citations and publications.

Interestingly, the journal with more publications is not necessarily the most widely cited, as is the case of *Solar Energy,* which has the largest number of cited articles (719 citations), but ranks in the fourth position regarding the amount of publications. Analogously, *Renewable Energy* is the journal with the largest number of publications, totaling 30, but it ranks in the 15th position in terms of citations, with 257 citations (Table 1).

5.4. Analysis of major authors

By looking at the names of all authors in each article, it is possible to list the publications and citations by author. Table 2 shows the 15 authors with most widely cited articles among 3169 different authors of the 739 publications analyzed.

The 15 authors shown in Table 2 account for 6.8% of the analyzed

Table 1
Ranking of 15 journals in terms of citations and publications.

Publication Source	Citation Total	Citation Ranking	Papers Total	Paper Ranking	Citation / Paper
Solar Energy	719	1°	19	4°	37.84
Journal of Geophysical Research-Atmospheres	663	2°	6	16°	110.5
Advanced Functional Materials	557	3°	6	17°	92.83
Journal of The American Chemical Society	449	4°	9	9°	49.89
Applied Physics Letters	437	5°	7	13°	62.43
Journal of Applied Physics	411	6°	13	5°	31.62
Journal of Solar Energy Engineering	374	7°	8	12°	46.75
Physical Review B	350	8°	4	30°	87.5
Solar Energy Materials and Solar Cells	341	9°	23	3°	14.83
Energy Policy	300	10°	27	2°	11.11
Aquaculture	289	11°	1	119°	289
Journal of Atmospheric and Solar-Terrestrial Physics	270	12°	1	120°	270
Energy	269	13°	13	6°	20.69
Catalysis Today	259	14°	2	61°	129.5
Renewable Energy	257	15°	30	1°	8.57

Table 2
Ranking of 15 most widely cited authors.

Author	Citation Total	Citation Ranking	Papers Total	Paper Ranking	Citation / Paper
Lutsen, Laurence	668	1	11	1	60.7
Maes, Wouter	668	1	11	1	60.7
Vanderzande, Dirk	584	2	10	2	58.4
Kudret, Suleyman	436	3	8	3	54.5
Zhao, X. S.	368	4	3	8	122.7
Defour, Maxime	330	5	4	7	82.5
Van den Brande, Niko	330	5	4	7	82.5
Van Mele, Bruno	330	5	4	7	82.5
Abermann, Stephan	328	6	1	10	328.0
Manca, Jean	318	7	4	7	79.5
Centi, Gabriele	302	8	4	7	75.5
Perathoner, Siglinda	302	8	4	7	75.5
Lior, Noam	292	9	3	8	97.3
Lira-Cantu, Monica	263	10	6	5	43.8
Kesters, Jurgen	254	11	3	8	84.7

publications (739) and 24.6% of the total number of citations (16,848). "Lutsen, Laurence" and "Maes, Wouter" are the first in the ranking of most widely cited authors - with 668 citations, and also occupy the first position regarding the number of publications (11). Interestingly, these two authors worked together in all of the 11 articles assessed, despite the fact that other co-authors were involved. "Lutsen, Laurence" is a researcher at *IMEC, IMOMEC Ass Lab* and "Maes, Wouter" is from *Hasselt University*, both from Belgium. "Defour, Maxime", "Van den Brande, Niko" and "Van Mele, Bruno" are co-authors in the four publications mentioned in Table 2 and both are researchers at *Vrije Univ Brussel* in Belgium. "Centi, Gabriele" and "Perathoner, Siglinda", from the University of Messina, Italy, worked as partners in four articles. "Centi, Gabriele" is from the *Dept Ind Chem & Engn Mat* and "Perathoner, Siglinda" from *ELCASS European Associated Lab Catalysis & Surfac*. Special attention should be given to "Abermann, Stephan", researcher at *AIT-Austrian Inst Technol,* in Austria, as he is the author with the best citation to publication ratio among the top 15 authors, having published a single article with 328 citations.

A relevant aspect of the articles obtained from the search is the participation of several authors in the publications (Fig. 7). Seventy-five percent of the publications have three or more authors. In other words, there is a clear sign of partnership in the development of studies given the co-authorship identified in the analyzed articles.

Note that 39% of the assessed authors are affiliated with U.S. (20%) and Chinese (19%) research institutes or universities. Authors affiliated with German and Japanese research institutes or universities rank second (17%) (Fig. 8). These four countries (USA, China, Germany, and Japan) concentrate more than 50% of researchers who work with SE and OI simultaneously.

By evaluating the type of partnerships (co-authorship), among all organizations (companies, universities, or research centers) involved in publications on OI and SE and classified as "International", "National" or "Local". Similar classification was used by Lei et al. (2013) and Yu et al. (2016) as we adopted in this work: "International" cooperation takes place between different organizations from different countries; "National" cooperation occurs between different organizations within

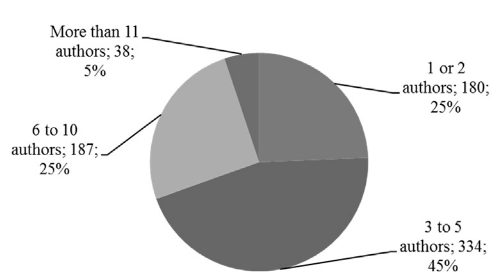

Fig. 7. Distribution of authors per publication.

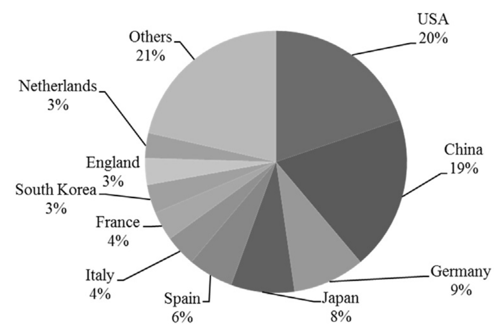

Fig. 8. Distribution of authors per source countries.

the same country; and "Local" cooperation takes place among authors from the same organization and same country. Of 3556 relationships, 1314 (36.95%) partnerships are international, 1176 (33.07%) are national, 954 (26.83%) are local, and 112 (3.15%) have no cooperation.

Table 3 shows the cooperation profile for top 10 countries with the largest number of authors who publish about OI and SE. Besides the types of cooperation mentioned earlier, the chart also displays cases in which no partnership was established (single author). These top 10 countries account for 2697 (75.8%) of total number of co-authorships.

As shown in Table 3, international cooperation is predominant in countries like the Netherlands (68.5%), Spain (48.8%), Germany (48.3%), and France (42.6%). Main international partners for these countries with high international cooperation are: the Netherlands → Spain, Germany, Belgium, Denmark and USA; Spain → Germany, USA and France; Germany → USA, Spain, France and Denmark; France → Germany, Spain, USA, Belgium and Denmark. On the other hand, national partnerships are common in Belgium (58.1%), Japan (47.7%), the USA (43.7%), France (42.6%), Italy (40.5%), South Korea (39.2%) and main national partners in these countries are: Belgium → IMEC, Vrije Univ Brussel and DICE Univ Catholique Louvain; Japan → Tokyo Denki Univ, Toyota Technol Inst, Tokyo Univ Agr & Technol and Toyota Cent Res & Dev Labs Inc; USA → Univ Delaware, Univ New Mexico, Univ Illinois, Natl Renewable Energy Lab, Univ Wisconsin, Univ Calif Santa Barbara and Univ Massachusetts. Lastly, China is characterized by a local cooperation pattern (47.3%) unlike the other countries that publish more articles about OI and SE; thus, its knowledge output is achieved by co-authorship within the same organization and within the country. In China, main local partners are Chinese Acad Sci, Univ Sci & Technol China, Zhejiang Univ and S China Univ Technol.

A relevant issue is that when analyzing absolute values, China has a large number of international cooperation than countries like Germany, France, the Netherlands and Spain. However, this percentage analysis proposes to indicate the predominance of cooperation

Table 3
Profile of cooperation between countries (co-authorship).

Country	Co-Authoring Relationship	International	National	Local	No Cooperation
Belgium	129	41.1%	58.1%	0.0%	0.8%
China	903	22.8%	29.1%	47.3%	0.8%
France	115	42.6%	42.6%	14.8%	0.0%
Germany	261	48.3%	24.5%	24.5%	2.7%
Italy	126	27.0%	40.5%	29.4%	3.2%
Japan	195	26.7%	47.7%	17.4%	8.2%
The Netherlands	73	68.5%	8.2%	20.5%	2.7%
South Korea	79	34.2%	39.2%	21.5%	5.1%
Spain	164	48.8%	17.1%	31.1%	3.0%
USA	652	40.2%	43.7%	11.7%	4.4%
Average	**75.8%**	**40.0%**	**35.1%**	**21.8%**	**3.1%**

type of each country between 2000 and 2014. This is not to say that China (or even the USA) are not relevant within international cooperation. On the contrary, analyzing only column international cooperation on Table 3, China and USA represent respectively 21.9% and 27.9% of total international cooperation, making these two countries very important players in this type of cooperation. However, when evaluating each country for the proposed period (row) and all kinds of cooperation, what can be observed is that China is still predominant in local cooperation.

Extending analysis of international cooperation for a future perspective (Table 4), we can find that China and USA will be the bigger players on SE international partnership. This forecasting was based on average of partnerships' number for five years' intervals and weighted ratio growing per each period. So, if China and USA that represent respectively 21.9% and 27.9% of international cooperation between 2000 and 2014, for period from 2015 to 2019, China may represent 41.8% and USA 20.6% of international cooperation about SE. This perspective is in same line of other researches (Gallagher, 2014; Zhang and Gallagher, 2016) and confirms the relevance of cooperation effort in SE field, specially it shows great important of China for the future of SE technology development.

5.5. Detailed analysis of major publications

An analysis of the most frequently cited documents allows us to verify that the 10 major articles (2% of the total of 739 publications) were cited 3897 times, accounting for 29.6% of all assessed citations. These documents contain at least one of the following terms in the analyzed topics (title, abstract, and keywords): *"solar energ*", "solar power", "solar radiation", "solar cell", "photovolt*", "transfer", "cooperat*", "collaborat*"* and *"R & D"*.

Table 4
International cooperation forecasting for top 10.

Country	Number of Partnerships			Ratio growing per period		Forecasting	
	P1	**P2**	**P3**	**R1**	**R2**	**P4**	**%P4**
Belgium	0	4	49	0.00	12.25	108	4.5%
China	1	10	195	10.00	19.50	1013	41.8%
France	4	6	39	1.50	6.50	65	2.7%
Germany	16	15	95	0.94	6.33	153	6.3%
Italy	4	1	29	0.25	29.00	166	6.8%
Japan	13	6	33	0.46	5.50	52	2.1%
The Netherlands	2	3	45	1.50	15.00	138	5.7%
South Korea	4	0	23	0.00	23.00	109	4.5%
Spain	3	17	60	5.67	3.53	123	5.1%
USA	36	19	207	0.53	10.89	499	20.6%

Legend: P1 = number of partnerships from 2000 to 2004; P2 = number of partnerships from 2005 to 2009; P3 = number of partnerships from 2010 to 2014; R1 = ratio between P2 and P1; R2 = ratio between P3 and P2; P4 = forecasting of partnerships to period 2015–2019; %P4 = percentage of international partnerships in P4.

The content of each of these publications was then assessed individually in order to classify them according to their association with the searched topics – SE and OI (Table 5). There was partial association between the development of SE technologies and OI management in only one of the articles: *"The SOLAR 2000 empirical solar irradiance model and forecasting tool."*

However, a different result was obtained (Table 6) after reordering the articles with terms strongly related to OI such as "*collaboration*" and "*cooperation*." In this more detailed analysis, 6 out of 10 articles, shown in boldface in Table 5, display some indication of OI practice by touching upon the terms "*collaboration*" and "*cooperation*" in a more explicit manner.

In these cases, the authors were from different research centers, which corroborates some cooperation in the development of studies on SE. In addition, this six articles were published recently (between 2011 and 2013), which may explain the small amount of citations of these articles, as indicated in the last column of Table 5.

5.6. Cooperation networks

By using SNA, it was possible to outline the network of relationships between organizations (universities, research centers, or companies) in which research into SE was conducted in partnership with other organizations (Fig. 9). The nodes represent the organizations and the edges are the publications undertaken by each of the authors affiliated with such organizations.

The network shows the formation of five main clusters indicated by A, B, C, D, and E. The largest cluster (A) consists of 77 organizations and it is predominantly composed of organizations from China and from other Asian countries, with some partnerships with U.S., Australian, Spanish, and UK organizations. This has a higher relevance for cooperation within the group itself, but it is also related to other clusters, especially (B). The major organizations of this group, according to the *PageRank* statistic, are: *Chinese Acad Sci, Zhejiang Univ, Natl Univ Singapore, Georgia Inst Technol,* and *Griffith Univ*.

Cluster (B) comprises 67 organizations, mostly from the USA. Cooperation occurs between these U.S. organizations and those from Japan, China, South Korea, and Germany at a lower frequency. According to the largest *PageRank*, the following organizations stand out in this cluster: *NASA, Washington University, Natl Inst Environm Studies, CALTECH,* and *China Meteorol Adm*. Interestingly enough, this cluster also works as a hub for the whole network, mediating relationships between different clusters, and due to such feature, it is said to be one of the most important clusters in the network.

Cluster (C) has 53 different organizations and it is more polarized in terms of partnerships between European organizations from Denmark, Germany, Belgium, France, and the Netherlands. The USA is an exception, cooperating substantially in the partnerships of this cluster. Cluster (C) also has a cooperation relationship cluster (D). The major organizations per *PageRank* are: *Natl Renewable Energy Lab, Fraunhofer Inst Solar Energy Syst ISE, Tech Univ Denmark, CNRS, IMEC,* and *Hasselt Univ*.

Table 5
Analysis of the 10 most frequently cited publications.

Paper Title	Citation Frequency	Terms found	Relationship with SE and OI
Asian dust events of April 1998	474	solar radiation, collaboration	No
Relating the morphology of poly (p-phenylene vinylene) / methanofullerene blends to solar-cell performance	435	solar cell, photovoltaic, cooperation	No
Quantum cutting by cooperative energy transfer in YbxY1-xPO4: Tb3+	316	solar cell, transfer, cooperation	No
High-efficiency polycrystalline CdTe thin-film solar cells	291	solar cell, photovoltaic, R & D	No
Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modem mariculture	289	solar energy, R & D	No
The SOLAR2000 empirical solar irradiance model and forecast tool	**270**	**solar radiation, collaboration**	**Yes**
Opportunities and prospects in the chemical recycling of carbon dioxide to fuels	248	solar energy, R & D	No
Black (pyrogenic) carbon: a synthesis of current knowledge and uncertainties with special consideration of boreal regions	243	solar radiation, cooperation	No
Space Weather Modeling Framework: A new tool for the space science community	228	Collaboration	No
Advances in parabolic trough solar power technology	225	solar power, R & D	No

Cluster (D) has 42 organizations, with a predominance of cooperation between organizations from European countries. In addition to partnerships within the same cluster, cooperation with organizations from group (C), as mentioned earlier, is also noteworthy. Organizations from countries such as Spain, Finland, England, Switzerland, India, and Turkey stand out in this group: *CIEMAT, VTT Tech Res Ctr Finland, Univ London Imperial Coll Sci Technol & Med, Paul Scherrer Inst, Natl Phys Lab,* and *Natl Metrol Inst*.

Finally, Cluster (E) is mostly comprised of U.S. organizations, among the 41 included in this group. Just like the other clusters, (E) has numerous partnerships with organizations from cluster (B). The main organizations include *Univ Calif Berkeley, Stanford Univ, Univ Arizona, Texas A & M Univ*, and *Univ Wisconsin*.

The features of each cluster strengthen the level of cooperation shown in Table 3, according to which China stands out in terms of local and national cooperation (cluster A). The USA is notable for its national and international partnerships (clusters B and E) and European countries (clusters C and D) are best known for their international partnerships.

With respect to the most important organizations concerning SE development, the reduced network (Fig. 10) displays top 15 organizations with the highest PageRank: *Chinese Acad Sci* and *Zhejiang Univ* (cluster A), *NASA, Univ Washington, Natl Inst Environm Studies* and *CALTECH* (cluster B), *Natl Renewable Energy Lab, Fraunhofer Inst Solar Energy Syst ISE, Tech Univ Denmark, CNRS, IMEC*, and *Hasselt Univ* (cluster C), and *Univ Calif Berkeley* (cluster E). Although not included in the groups analyzed previously, *Arizona State Univ* and *Harvard Univ* also belong with the major organizations in the SE cooperation network. It should be noted that the cooperation among the top 15 organizations is poor and that only *Chinese Acad Sci* and *Univ Calif Berkeley* work in partnership with *NASA*. The remaining organizations cooperate with each other if they are in the same cluster.

A cooperation network of publication authors was also built (Fig. 11). In this network, nodes represent authors and edges indicate collaborative works (co-authorship). Also, a SNA modularity function based was used to identify clustering - nodes that relate to each other and work like a community. It can be seen in Fig. 11, through different colors, cooperation network clusters between SE publications authors. Note in this network the existence of a large amount of isolated clusters without any connections between them. It may lead to a conclusion that these authors, and their respective organizations, already have well-defined groups for SE cooperation which seldom interact with each other. The opposite of it would be a much more branched network in which these clusters of different colors would have connections between them and there would be even more broad in the cooperation for SE technology development. The objective of this work is not to analyze each cluster, but following is an overview of main authors and their cooperative relationships.

Fig. 12 shows the 15 major authors in this previous network. The PageRank statistic used in SNA displays the most relevant nodes by measuring the qualitative and quantitative importance of the network. The authors shown in Fig. 12 are the most influential in the SE network as shown by the PageRank values. Those authors partner with several other authors and such partnerships are set up with other important authors.

Interestingly enough, only “Lutsen, Laurence”, “Maes, Wouter” and “Vanderzande, Dirk” listed in Table 2 are among the top 15 authors, according to the SNA method. Therefore, the ranking shown in the table indicates important authors based on the citations of their works and the selection of the top 15 displayed in Fig. 12 shows the most important authors from the perspective of cooperation in the development of SE technologies.

6. Conclusion and policy implications

When analyzing the results of OI and SE studies, several potential contributions in these areas can be presented and they showed in two parts: first, discussion and conclusions about previous results; second, some recommendations which can imply in policy implications and possible actions to improve solar energy researches and technology development for the future.

Firstly, the bibliometric analysis of articles on SE and OI published in *Web of Science* database led to the conclusion that combining terms related to SE to terms commonly used in OI literature, yielding 739 publications between years 2000 and 2014. From this database, it was possible to find that the number of SE papers has progressively increased for the past 15 years, and so has the number of citations of these papers, which indicates the interest of scientific community in SE area. By using terms “cooperation” and “collaboration” as proxy to map OI, papers that contain references to SE, “cooperation” and “collaboration” are recent, published between 2011 and 2013, and look into cooperation and collaboration aspects in a more assertive manner, explicitly stating that the development of SE technologies has taken place through collaboration and cooperation between researchers and institutions. Therefore, it may be concluded that the assumption made holds, as it is possible to identify indirect evidence of OI in publications about the development of SE technologies in references to collaboration and cooperation between entities. It was not possible to gather direct evidence as none of the selected articles explicitly uses this innovation management model.

From the perspective of scientific journals, it is interesting to note that among the most relevant journals evaluated, there are a variety of other knowledge areas involved in SE theme, from specific journals of SE area such as "Solar Energy", "Renewable Energy", "Energy Policy", to journals of different disciplines such as "Journal of Geophysical

Table 6
Analysis of 10 publications with higher frequency of terms related to OI.

Paper Title	Frequency of "*collaboration*" and "*cooperation*" terms	Terms found	Relationship with SE and OI	Citation Frequency
Technological collaboration patterns in solar cell industry based on patent inventors and assignees analysis	**23**	**Collaboration, Cooperation, Solar Cell**	**Yes**	**3**
International Collaboration Activity Index: Case study of dye-sensitized solar cells	**17**	**Collaboration, Solar Cell**	**Yes**	**0**
The unbalanced performance and regional differences in scientific and technological collaboration in the field of solar cells	**8**	**Collaboration, Solar Cell**	**Yes**	**3**
Sustainable Urban Design: A solar strategy for a sustainable city	8	Cooperation, Solar Energy, Solar Radiation	No	0
Collaboration network and pattern analysis: case study of dye-sensitized solar cells	**7**	**Collaboration, Solar Cell**	**Yes**	**0**
Energy transfer mechanism for downconversion in the (Pr3+, Yb3+) couple	5	Cooperation	No	31
Quantum cutting by cooperative energy transfer in YbxY1-xPO4: Tb3+	4	Cooperation, Solar Cell	No	316
Photoelectric Cooperative Induced Wetting on Aligned-Nanopore Arrays for Liquid Reprography	4	Cooperation	No	15
The research profiling method applied to nano-enhanced, thin-film solar cells	**4**	**Collaboration, Cooperation, Solar Energy, Solar Cell**	**Yes**	**10**
Entry Conditions, Firm Strategies and Their Relationships to the Innovation Performance of an Emerging Green Industry The Case of the Solar Cell Industry	**4**	**Collaboration, Solar Cell**	**Yes**	**3**

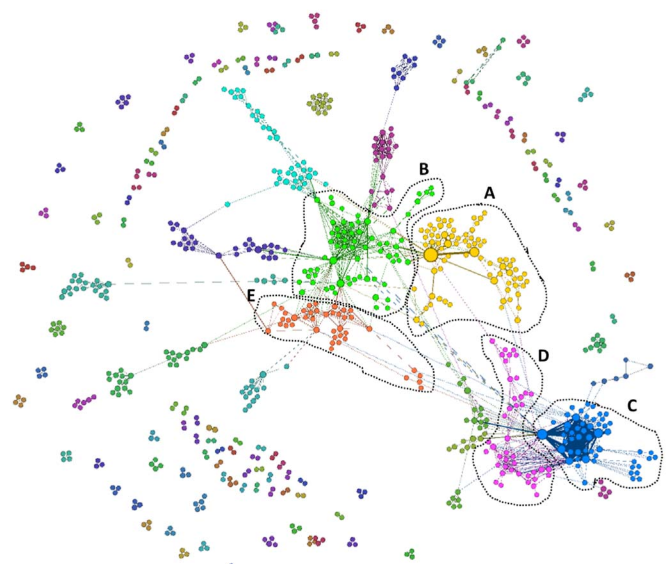

Fig. 9. Co-authorship (cooperation) network of organizations for which authors work.

Research-Atmospheres", "Advanced Functional Materials", "Journal of the American Chemical Society". This shows the large scope of research interest in ES subject and possible interconnection between different knowledge areas.

About authors, 75% of papers have three or more authors which also show the interest of scientific community in knowledge exchange and collaboration in SE research. Most relevant authors have follow contributions to SE area: Laurence Lutsen, Wouter Maes, Dirk Vanderzande (Hasselt University, Inst Mat Res IMO IMOMEC) and Maxime Defour, Niko Van den Brande, Bruno Van Mele (Vrije Univ Brussel, Phys Chem & Polymer) contribute to topics "Organic Photovoltaic Devices", "Polymers (Functionalized poly, Conjugated and Block)", "Bulk and Solar Cells heterojunctions", "Morphology" and "Thermal-stability". Main topics researched by authors Gabriele Centi and Siglinda Perathoner (University of Messina, Italy) are "Photo and Photoelectrochemical Conversion", "Solar Fuels" and "Catalysis". Other relevant author based on pagerank relevant are Li Li, Xiantao Wei, Min Yin (Univ Sci & Technol China, Dept Phys) which main topic researched are "Energy-Transfer", "Luminescence", "Photoluminescence" and "Optical Materials".

Cooperation profile of SE researchers shows predominance of international cooperation for European countries, national cooperation for the USA and some European countries, and local cooperation for China. It can be clearly seen that there exists cooperation in the researches of SE technologies both at the national (same country and different institutions) and international levels (different countries and different institutions). International cooperation is predominant in countries like the Netherlands (68.5%), Spain (48.8%), Germany (48.3%), France (42.6%) and their main partners are: the Netherlands (Spain, Germany, Belgium, Denmark and USA); Spain (Germany, USA and France); Germany (USA, Spain, France and Denmark); France (Germany, Spain, USA, Belgium and Denmark). Prevailing national partnerships, we found Belgium (58.1%), Japan (47.7%), the USA (43.7%), France (42.6%), Italy (40.5%) and South Korea (39.2%). China is characterized by a predominant local cooperation in SE publications (47.3%) from 2000 to 2014. Analyzing only publications of international cooperation, China and USA represent respectively 21.9% and 27.9% of total international cooperation, making these two countries very important players and that have more international cooperation than countries like Germany, France, the Netherlands and Spain. Forecasting about international cooperation for next four years, China may represent 41.8% and USA 20.6% of international cooperation about SE for period from 2015 to 2019.

Still based on cooperation analysis, the most influence organiza-

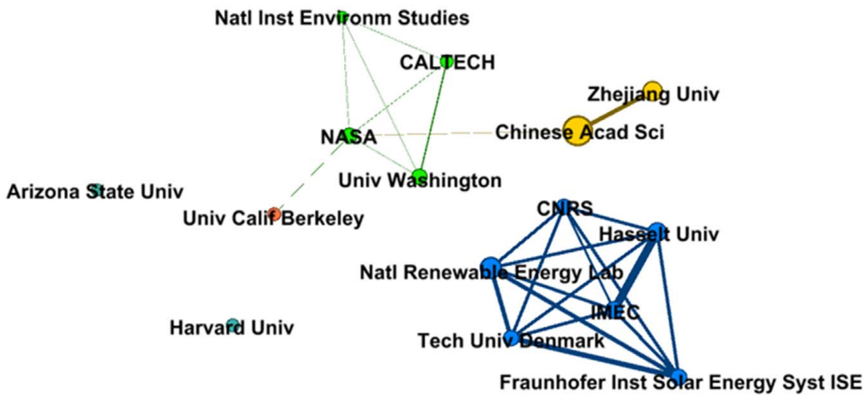

Fig. 10. The 15 organizations with the highest pagerank.

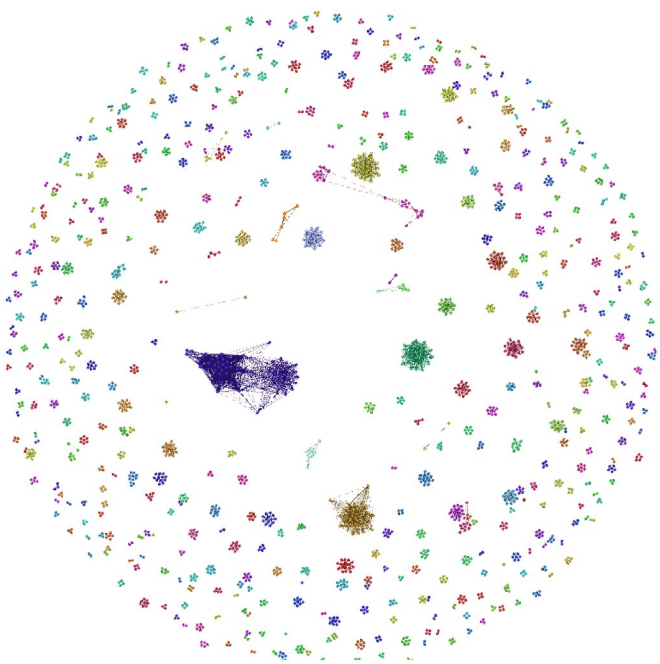

Fig. 11. Co-authorship (cooperation) network of authors.

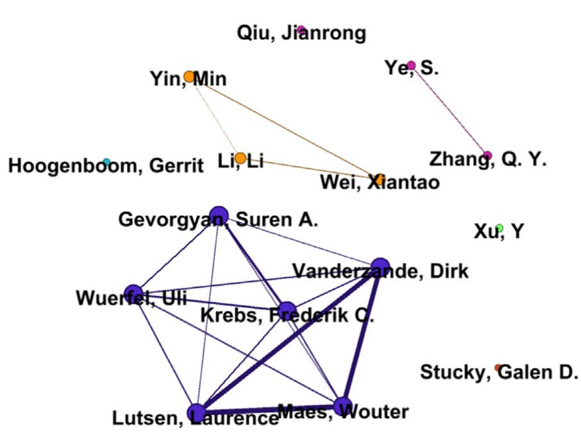

Fig. 12. Top 15 authors with the highest pagerank.

tions in SE research are: Chinese Acad Sci and Zhejiang Univ (cluster A), NASA, Univ Washington, Natl Inst Environm Studies and CALTECH (cluster B), Natl Renewable Energy Lab, Fraunhofer Inst Solar Energy Syst ISE, Tech Univ Denmark, CNRS, IMEC, and Hasselt Univ (cluster C), and Univ Calif Berkeley (cluster E). These organizations are in a low level of cooperation, and just Chinese Acad Sci and Univ Calif Berkeley work in partnership with an organization in a different cluster of them.

Secondly, a set of recommendations based on previous results should be provided to construct a better environment for cooperation and to improve Solar Energy researches: (i) public policy which encourages cooperation between research centers and companies from different countries could contribute to greater internationalization research; (ii) promote the interdisciplinarity of research topics which can further increase cooperation between researchers, research centers, firms, as well as extend the applicability of ES technologies; (iii) establish research groups and routines of technology analysis and evolution (technology forecasting) to understand main actors and cooperation profile in SE; (iv) define some partnership program, especially with countries such as China and USA, which currently has greater centrality and dominance in cooperation network of SE research; (v) due the increase interest of SE research last years, provide special funding for firms to transform theses researches in technology applied.

It is important to mention that shortcomings of the present analysis should be investigated in further studies, as the investigation was limited to data obtained from *Web of Science* and this electronic search may indirectly have a selection bias. Moreover, the use of this database restricts the object of investigation by considering only articles indexed by JCR. The amount of data on financing agencies and on the organizations to which the authors of the assessed articles belong was not enough to extrapolate the analyses and obtain additional conclusions and, consequently, such conclusions were disregarded. Future studies should seek to include a larger database, using other indexes in addition to JCR. They should also assess issues related to co-citation, knowledge networks, and collaboration networks between countries and institutions, evaluate the predominance of publications according to other criteria, such as clustering by continent or by level of economic development. These future analyses could complement this study and corroborate the evidence of OI use in the development of SE technologies through other methods.

References

Abulrub, A.H.G., Lee, J., 2012. Open innovation management: challenges and prospects. Proc.-Soc. Behav. Sci. 41, 130–138.

Albino, V., Ardito, L., Dangelico, R.M., Petruzzelli, A.M., 2014. Understanding the development trends of low-carbon energy technologies: a patent analysis. Appl. Energy 135, 836–854.

Bastian, M., Heymann, S., Jacomy, M., 2009. Gephi: an open source software for exploring and manipulating networks. Int. Conf. Web Soc. Media 8, 361–362.

Belter, C.W., Seidel, D.J., 2013. A bibliometric analysis of climate engineering research. Wiley Interdiscip. Rev.: Clim. Change 4 (5), 417–427.

Bianchi, M., Campodall'Orto, S., Frattini, F., Vercesi, P., 2010. Enabling open innovation in small-and medium-sized enterprises: how to find alternative applications for your technologies. R & D Manag. 40 (4), 414–431.

Braun, T., Schubert, A.P., Kostoff, R.N., 2000. Growth and trends of fullerene research as reflected in its journal literature. Chem. Rev. 100 (1), 23–38.

Chesbrough, H., 2003b. The logic of open innovation: managing intellectual property. Calif. Manag. Rev. 45 (3), 33–58.
Chesbrough, H.W., 2003a. Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press.
Chesbrough, H.W., 2003b. The era of open innovation. MIT Sloan Manag. Rev. 44 (3), 35–41.
Chesbrough, H.W., 2011. Bringing open innovation to services. MIT Sloan Manag. Rev. 52 (2), 85.
Chesbrough, H., Crowther, A.K., 2006. Beyond high tech: early adopters of open innovation in other industries. R & D Manag. 36 (3), 229–236.
Chesbrough, H., Vanhaverbeke, W., West, J. (Eds.), 2006. Open Innovation: Researching A New Paradigm. Oxford university press.
Dong, B., Xu, G., Luo, X., Cai, Y., Gao, W., 2012. A bibliometric analysis of solar power research from 1991 to 2010. Scientometrics 93 (3), 1101–1117.
Du, H., Li, N., Brown, M.A., Peng, Y., Shuai, Y., 2014. A bibliographic analysis of recent solar energy literatures: the expansion and evolution of a research field. Renew. Energy 66, 696–706.
Du, H., Wei, L., Brown, M.A., Wang, Y., Shi, Z., 2013. A bibliometric analysis of recent energy efficiency literatures: an expanding and shifting focus. Energy Effic. 6 (1), 177–190.
Fahimnia, B., Sarkis, J., Davarzani, H., 2015. Green supply chain management: a review and bibliometric analysis. Int. J. Prod. Econ. 162, 101–114.
Gallagher, K.S., 2014. The Globalization of Clean Energy Technology: Lessons from China. MIT press.
Garg, K., Sharma, P., 1991. Solar power research: a scientometric study of world literature. Scientometrics 21 (2), 147–157.
Gassmann, O., 2006. Opening up the innovation process: towards an agenda. R & D Manag. 36 (3), 223–228.
Huizingh, E.K., 2011. Open innovation: state of the art and future perspectives. Technovation 31 (1), 2–9.
Hutter, K., Hautz, J., Füller, J., Mueller, J., Matzler, K., 2011. Communitition: the tension between competition and collaboration in community-based design contests. Creat. Innov. Manag. 20 (1), 3–21.
IEA - International Energy Agency, 2014a. Energy Technology Perspectives - Executive Summary. Available in: ⟨http://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives_ES.pdf⟩. (Accessed 26 December 2014).
IEA - International Energy Agency, 2014b. IEA Technology Roadmaps for Solar Electricity. Available in: ⟨http://www.iea.org/media/freepublications/technologyroadmaps/solar/Launchsolarroadmaps2014_WEB.pdf⟩. (Accessed 20 March 2016).
IEA - International Energy Agency, 2015. IEA Electricity Information Statistics. OECD - Electricity and heat generation. Available in: ⟨http://stats.oecd.org/BrandedView.aspx?Oecd_bv_id=elect-data-en & doi=data-00457-en#⟩. (Accessed 20 April 2015).
Jackson, M. O., 2010. *Social and economic networks*. Princeton university press.
Kalogirou, S.A., 2004. Solar thermal collectors and applications. Progr. Energy Combust. Sci. 30 (3), 231–295.
Lei, X.P., Zhao, Z.Y., Zhang, X., Chen, D.Z., Huang, M.H., Zheng, J., Zhao, Y.H., 2013. Technological collaboration patterns in solar cell industry based on patent inventors and assignees analysis. Scientometrics 96 (2), 427–441.
Lichtenthaler, U., 2008. Open innovation in practice: an analysis of strategic approaches to technology transactions. Eng. Manag. IEEE Trans. 55 (1), 148–157.
Lichtenthaler, U., 2011. Open innovation: past research, current debates, and future directions. Acad. Manag. Perspect. 25 (1), 75–93.
Moed, H.F., 2006. Citation Analysis in Research Evaluation 9. Springer Science & Business Media.
Narin, F., Olivastro, D., Stevens, K.A., 1994. Bibliometrics/theory, practice and problems. Eval. Rev. 18 (1), 65–76.
Newman, M., 2010. Networks: An Introduction. Oxford University Press.
Oslo Manual, 2005. Guidelines for collecting and interpreting innovation data. Organization for Economic Cooperation and Development, OECD.
Page, L., Brin, S., Motwani, R., Winograd, T., 1999. The PageRank Citation Ranking: Bringing Order to the Web. Stanford InfoLab.
Porto, G.S., Costa, P.R., 2013. Abordagens de Inovação. In: Porto, Geciane Silveira. (Org.). Gestão da Inovação e Empreendedorismo (Vol 1, p. 45-77) Rio de Janeiro: Elsevier.
Rahman, H., Ramos, I., 2010. Open innovation in SMEs: from closed boundaries to networked paradigm. Issues Inf. Sci. Inf. Technol. 7, 471–487.
Schneider, J.W., Borlund, P., 2004. Introduction to bibliometrics for construction and maintenance of thesauri: methodical considerations. J. Doc. 60 (5), 524–549.
Schumpeter, J.A., 1984. Capitalismo, socialismo e democracia. Zahar, Rio.
Su, H.N., Lee, P.C., 2012. Framing the structure of global open innovation research. J. Informetr. 6 (2), 202–216.
Reuters, Thomson, 2015. - Top 100 Global Innovators - Honoring the World Leaders in Innovation. Available in: ⟨http://images.info.science.thomsonreuters.biz/Web/ThomsonReutersScience/%7Beb621c66-e238-4994-b1b5-9f5f9f897a75%7D_Thomson_Reuters_Top100_Global_Innovators_final.pdf⟩. (Accessed 20 March 2016).
Van de Vrande, V., De Jong, J.P., Vanhaverbeke, W., De Rochemont, M., 2009. Open innovation in SMEs: trends, motives and management challenges. Technovation 29 (6), 423–437.
Wang, Y., Vanhaverbeke, W., Roijakkers, N., 2012. Exploring the impact of open innovation on national systems of innovation - A theoretical analysis. Technol. Forecast. Soc. Change 79 (3), 419–428.
Wei, Y.M., Mi, Z.F., Huang, Z., 2015. Climate policy modeling: an online SCI-E and SSCI based literature review. Omega 57, 70–84.
Yi, H., Xi, Z., 2008. Trends of DDT research during the period of 1991 to 2005. Scientometrics 75 (1), 111–122.
Yu, H., Wei, Y.M., Tang, B.J., Mi, Z., Pan, S.Y., 2016. Assessment on the research trend of low-carbon energy technology investment: a bibliometric analysis. Appl. Energy 184, 960–970.
Zhang, F., Gallagher, K.S., 2016. Innovation and technology transfer through global value chains: evidence from China's PV industry. Energy Policy 94, 191–203.