LESSONS LEARNED ABOUT TECHNOLOGY MONITORING IN THE SOLAR PHOTOVOLTAIC ENERGY SEGMENT

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ABSTRACT

The practice of using technology monitoring to keep track of technological advances is increasingly valued, and its systematic use is understood as essential to business in the new knowledge economy. The structuring of the technological monitoring process has become a growing need for organizations to keep up with the significant and rapid changes of technology in their core business and to better understand its business impact in order to support the decision-making process of companies.

An effective technology monitoring process should be based on a company's business needs and on the information required for the fitting to strategic guidelines. This encompasses the right selection of databases, the establishment of the search strategy and keywords to be applied, the screening of the retrieved information, the analysis and consolidation of this information, and the right format and display of the relevant data and future trends to help the management decision.

Photovoltaic solar energy reached the capacity of 139 GW in 2013, being an expanding market with a high number of government funding projects in the United States and in the European Union. Therefore, a survey was carried out about the new technologies and related business scenarios for this kind of power generation, using technology monitoring tools.

Energy generation via photovoltaic cells has been known for a long time, since the Becquerel studies in the XIX century. Solar photovoltaic energy enables the generation of distributed electric energy, preventing long transmission and distribution lines, besides being a silent energy source that can be easily integrated into buildings without the need of additional installation areas; for these reasons, its application is being fostered by government programs.

The main step of the technology monitoring methodology is discussed, and the peculiarities and difficulties encountered in the process are pointed out. A survey of the scientific and technological developments in this area of knowledge was carried out, using patents and scientific papers with the time frame from the beginning of 2008 to the end of 2013. The lessons learned in this process and the major facilitating factors and difficulties for the retrieval, screening and analysis of the information collected are reported.

Key words: technology monitoring, solar photovoltaic energy, innovation management, R&D management, decision-making support

INTRODUCTION

The world energy matrix is predominantly based on non-renewable sources, with crude oil, natural gas and coal being its main contributors. Nowadays, there is a worldwide effort to reduce the environmental impact, mostly that caused by the burning of fossil fuels. In this sense, the search for clean technologies and renewable energy sources such as solar energy, wind energy, hydropower, tidal power, biomass and geothermal energy is presented as an alternative solution to address the harmful nature and current limited primary sources of energy.

In the last years, solar energy has been in evidence as one of the most promising options, substantially expanding its market, with gains in large production scale and cost reduction. Moreover, photovoltaic (PV) solar energy makes possible the generation of the electric power in a distributed manner, preventing the use of long transmission and distribution lines, besides the possibility of being integrated into the buildings in urban areas (Torres, 2012).

Solar PV energy is obtained through the direct conversion of light into electricity. The photovoltaic effect, that is, the creation of voltage or electric current in a material upon exposure to light, was first observed by French physicist A. E. Becquerel in 1839. It consists of built-in potential difference (Galvani potential) at the extremities of a semiconductor material structure, produced by the absorption of incident light. The PV cells, mainly made of silicon, are the best elements for a photovoltaic system. The cells produce low electric potential, about 1.5 W, but can be linked in series and/or parallel, forming photovoltaic modules, in which the generated power is about 50 to 100 W; or photovoltaic panels, formed by interlinked electric modules that generate higher power, or even arrangement/PV matrixes, which are full generation units, encompassing a number of PV modules and panels (Medeiros, 2008).

The use of solar PV energy has been fostered in several countries by means of government programs. The search for novel, non-pollutant sustainable energy sources is promoting intense R&D activity. Alves (2014) states that the solar PV energy is the fastest growing energy in the world. Considering the period 1995 to 2013, overall production capacity increased by more than 200 times. According to data released by the European Photovoltaic Industry Association (EPIA), the PV capacity installed in the world was about 139 GW at the end of 2013.

Figure 1 shows how the world solar PV capacity has increased along the years.

It is noticeable that the PV energy market is in full expansion, showing steady growth over the past few years. Although solar energy is the most abundant among the renewable sources, its cost per installed kW is still high, mainly due to the high manufacturing cost of PV panels. In this process, quality improvement of the material used and the reduction of the cost of the equipment are the biggest challenges to be overcome for wide application of this source of energy.

The motivation to publish this work came from the technology monitoring studies about several renewable energy sources, carried out by the Chemical Industry Information System

(SIQUIM) of the Federal University of Rio de Janeiro. The main energies studied were second and third generation bioethanol, concentrated solar energy, and solar PV energy. This latter study presented a much higher number of patent applications and technical articles than the others, spotlighting the high interest in the subject in several countries and revealing that a series of R&D investments for solar PV technology development is being carried out.

Therefore, the main objective of this work is to show and discuss the main steps of the technology monitoring process for solar PV energy, focusing on the search strategies for the different data bases, considering the patent applications and scientific articles issued from the beginning of 2008 until the end of 2013.

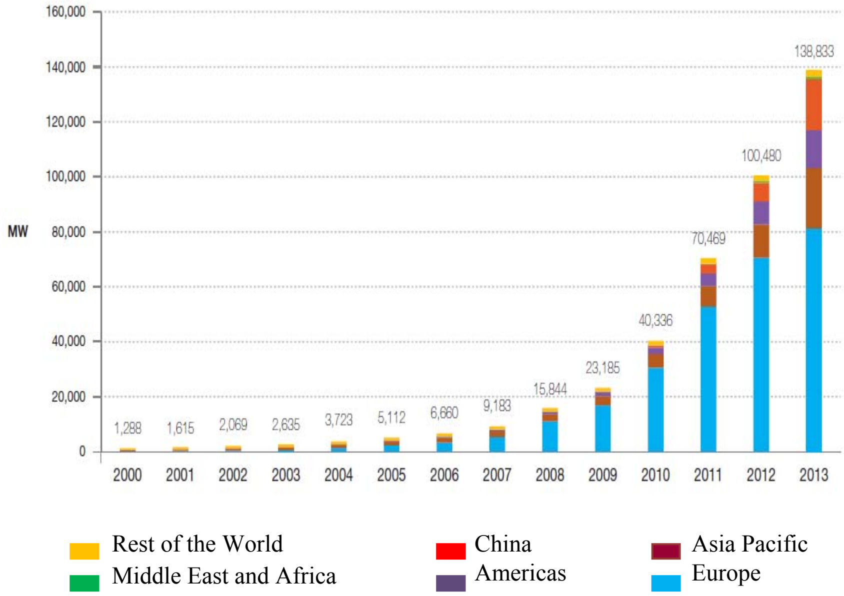

Figure 1: Evolution of the worldwide installed Solar PV capacity in MW, Source: EPIA, 2014

APPLIED METHODOLOGY

In order to perform a study of technological forecasting by literature review, it is necessary initially to identify the relevant information to be retrieved, then select the database and draw up the search strategy. As mentioned above, the information sources were applied on granted patents and scientific papers, which permitted to survey their technological development and R&D intensity. The selection of the database considered the following aspects:

- Search objective – the database should be in alignment with the kind of relevant information to be retrieved, considering the knowledge area in study;
- Fields available for search - some features can significantly minimize the time spent on the search;
- Options for using Boolean operators, truncation or other wildcards;
- Search cost - there are free databases and paid ones, which generally provide some type of additional analysis;

- Scope and coverage of the base.

The chosen database must be comprehensive enough to cover the majority of the data available and sufficiently describe the subject of interest, but narrow enough to ensure that there is no distortion in the analysis, reducing the number of irrelevant records. The search strategy can be defined as the technique that enables matching the question to the provided reply using the information stored in a database (Lopes, 2002 *apud* Faria *et al.*, 2014). As is well known, a search strategy can be formulated from keywords identified in the title and/or summary of a publication; from the selection of a particular inventor, company or institution; and from the restriction of a period of time, among other possibilities. It is very common the combination of two or more types of information to reduce the volume of data retrieved. Moreover, care should be taken to identify peculiarities related to the theme in study.

It will be discussed next the methodologies adopted in each type of survey for the prospective study about the solar PV energy.

Patent Document (granted or published)

The selected patent database was the *Derwent Innovation Index (DII)*, which is an internationally well-known source. The retrieval of documents is easily done and it contains its own classification system, called the Derwent Manual Code, in which the technological knowledge is divided in twelve sections that are further subdivided. The classification is performed by its own revisers and the strategy based on the Manual Code allows an advanced search with a higher level of details and accuracy, since these codes enhance the most significant aspects of an invention and its commercial application. In this study, 26 Derwent Codes were used, which are listed in Table 1.

Table 1: Codes and their respective areas of technology: Patents

Derwent Manual Codes	Description
L04-E05D	Photovoltaic Devices, Photoelectric Cells
U12-A02A1	Single Solar Cell
U12-A02A2	Semiconductor Materials And Structures For Solar Cells
U12-A02A2A	Solar Cells With AII-BVI Compounds
U12-A02A2B	Solar Cell With AIII-BV Compounds
U12-A02A2C	Solar Cell With AIV Compounds
U12-A02A2D	Solar Cells With Organic Materials
U12-A02A2E	Solar Cell With Chalcogenide/Chalcopyrite Compounds
U12-A02A2F	Solar Cell With Amorphous, Polycrystalline Semiconductor
U12-A02A2Q	Solar Cell Structure
U12-A02A2X	Semiconductor Materials For Solar Cells – Other
U12-A02A4	Solar Cell Substrate, Electrode And Packaging
U12-A02A4A	Solar Cell Electrodes
U12-A02A4B	Solar Cell Substrate Details
U12-A02A4C	Multifunction Tandem Solar Cells
U12-A02A4D	Covering Layers For Solar Cells

Derwent Manual Codes	Description
U12-A02A4E	Packaging Aspects For Solar Cells
U12-A02A5	Assemblies Of Solar Cells
U12-A02A7	Power Transfer, Circuitry Arrangements For Solar Cells
U12-A02A8	Dye Sensitized Solar Cells
X15-A02	Direct Conversion Photovoltaic Panel Details; Solar/Photovoltaic Cells Details
X15-A02A	Single Cells
X15-A02B	Assemblies Of Cells
X15-A02C	Solar / Photovoltaic Panel Details
X15-A02F	Organic Solar Cell
X15-A02X	Other Solar / Photovoltaic Panels / Cells Details

Another search strategy was formulated using the field keywords in the title and/or abstract of the documents. In this strategy words like arrange, array, assemble, battery, circuit, device, dye, electrode, film, junction, layer, module, pack, panel, semiconductor, silic, silicon, storage, solar cell, substrate, tandem, thermo, photovoltaic and/or track were combined among them.

Comparing a strategy based on a set of keywords found in the title and/or summary of the document and the strategy using a combination of Derwent Codes, it was observed that the latter retrieved a greater volume of relevant documents directly linked to the subject, while the former didn't show sufficient robustness.

The search period encompasses patents applications with priority year from 2008 to 2012.

Scientific Articles

The selected database for the retrieval of scientific papers was the *Web of Science*, a database for subscribers only, whose advantage is the fact that it is a multidisciplinary basis that indexes only the most often cited journals in their respective areas, therefore, the most relevant ones. Today this database has more than 9,000 indexed journals, and it includes articles dating from 1945 to the present day. Moreover, it allows exporting the data of the retrieved articles to a software like *Vantage Point*® for further treatment.

Different from the search strategy for the applied patent, the retrieval of articles was based only on keywords. After studying the theme, it was possible to identify which words would contribute to the retrieval of relevant publications. The search was comprehensive, because the main task was to retrieve the largest number of articles possible, and keywords such as photovoltaic, solar cell and synonymies were used. The same search period for the patent documents was adopted. After this step, documents were incorporated into the software *Vantage Point*® for analysis and treatment of information.

RESULTS AND ANALYSIS OF SCIENTIFIC ARTICLES DOCUMENTS

The search for scientific papers retrieved 59,755 documents, a much larger amount in comparison to another previous search for concentrated solar energy conducted by SIQUIM, which retrieved a number of articles about a tenth of the solar PV. This set of articles made it possible to carry out a series of analyses to identify some peculiarities of the sector.

A set of data was plotted to make the analysis of the specific parameters related to the documentation easier. In Figure 2 the evolution of the publications over time, considering the year of publication, is presented. It clearly shows a growing trend in publications, which reflects the present interest in the subject.

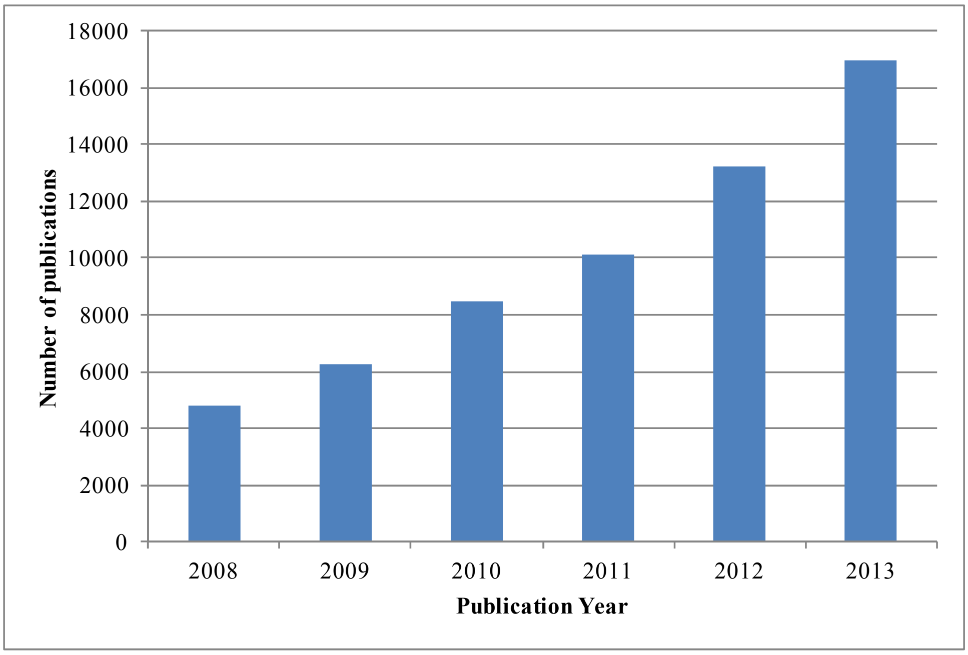

Figure 2: Temporal evolution of published scientific articles

In addition to the temporal evolution analysis, a survey related to the main countries involved in the development of PV energy was made, which considered the institution's country of origin of the main author. Below, in Figure 3, are ranked the 25 countries that stood out in number of publications, being Poland the last with 348 documents.

It is easy to realize a strong Chinese and American leadership. In addition to the investment in R&D, China has also made substantial progress in the application of this technology. Data released by the European Photovoltaic Industry Association (EPIA) showed that China got the record of PV cells installation in 2013, when 11.8 GW of capacity were installed, beating the previous records of Germany. For three consecutive years Germany maintained an annual standard of installing capacity around 7.4 - 7.6 GW, leading to a total installed capacity of 35.7 GW; however, recent regulatory changes in the country led to a market fall, and Germany got the fourth position in the ranking of installed capacity, adding only 3.3 GW in 2013. This year, the Chinese generation capacity reached 18.6 GW (EPIA, 2014) and the construction of the largest solar energy plant in the world was announced by the Chinese government. This project will take four years to be completed, but some panels already started to operate in 2014 (Rosa *et al.*, 2014).

Considering that solar PV energy is more expensive than conventional ones, it's important to understand the government policies that stimulate this new market. Therefore, information about governmental programs was also gathered.

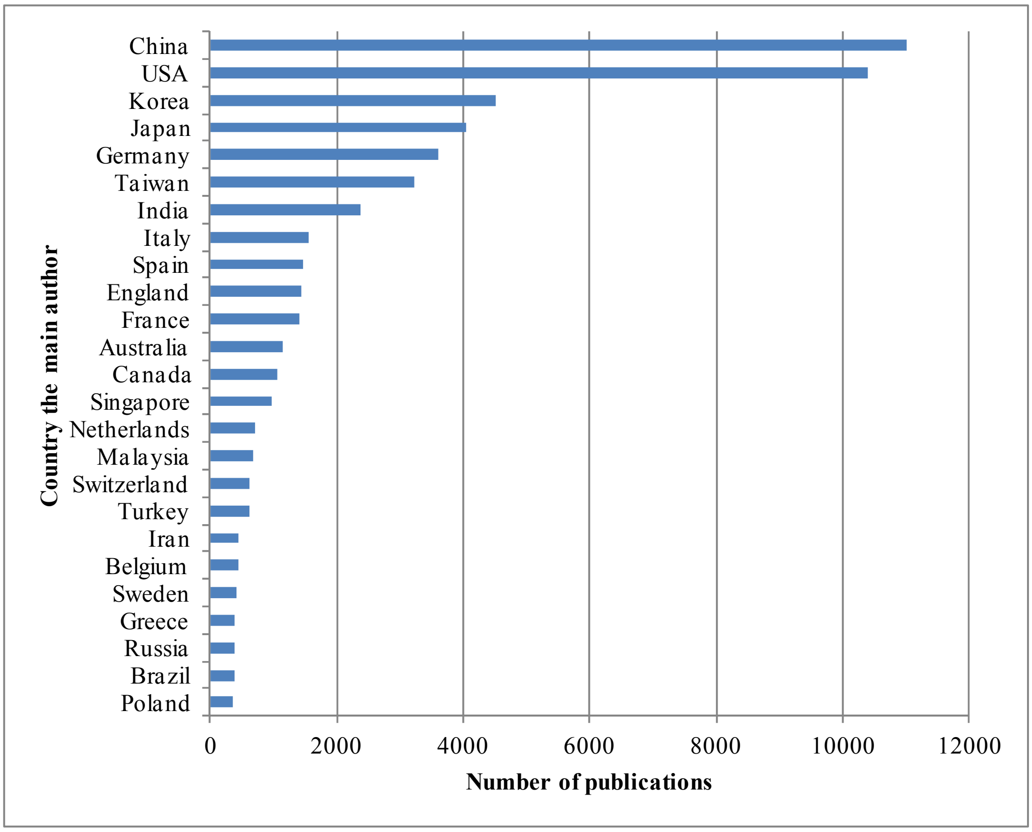

Figure 3: Ranking of the leader countries in PV energy R&D activities (Based on the institution's country of origin of the main author)

The United States has a series of incentive programs for solar PV energy. The technology research in this area of knowledge is not a recent achievement: it started in 1996, when the Department of Energy (DoE) created the National Center for Photovoltaics, whose goal was to keep the PV industry competitive. The DoE also created the *Solar America Initiative*, in 2006, whose main task was to reduce the costs of solar PV technologies. In 2011, the DoE launched another initiative, called the *SunShot*, whose main objective is to make the cost of solar energy competitive with other energy sources until 2020, encompassing both PV and concentrated solar energy technologies. These American government investments had an output of several technology development projects and, in 2008, the DoE announced a $ 17.6 million dollar investment in six incubated companies, as part of the *Solar America Initiative* (ABINEE, 2012).

It's worth to mention that, besides China, two other Asian countries, South Korea and Japan, are in third and fourth leading positions, respectively. According to information from the president of the Japan Photovoltaic Energy Association, the Fukushima nuclear disaster in 2011 led to a change in the medium- and long-term energy policy of that country, with a focus on security, stability, efficiency, and ecology (Matsubara, 2014; Kuramochi, 2015). In this regard, Figure 4, which plots the temporal evolution of Japanese scientific articles, shows that the number of documents almost doubled after 2011, that is, the average of the precedent years (2008 to 2010) was 501 articles, and for the subsequent (2012-2013) the average reached 963. This kind of analysis for patent applications is impaired due to the secrecy period.

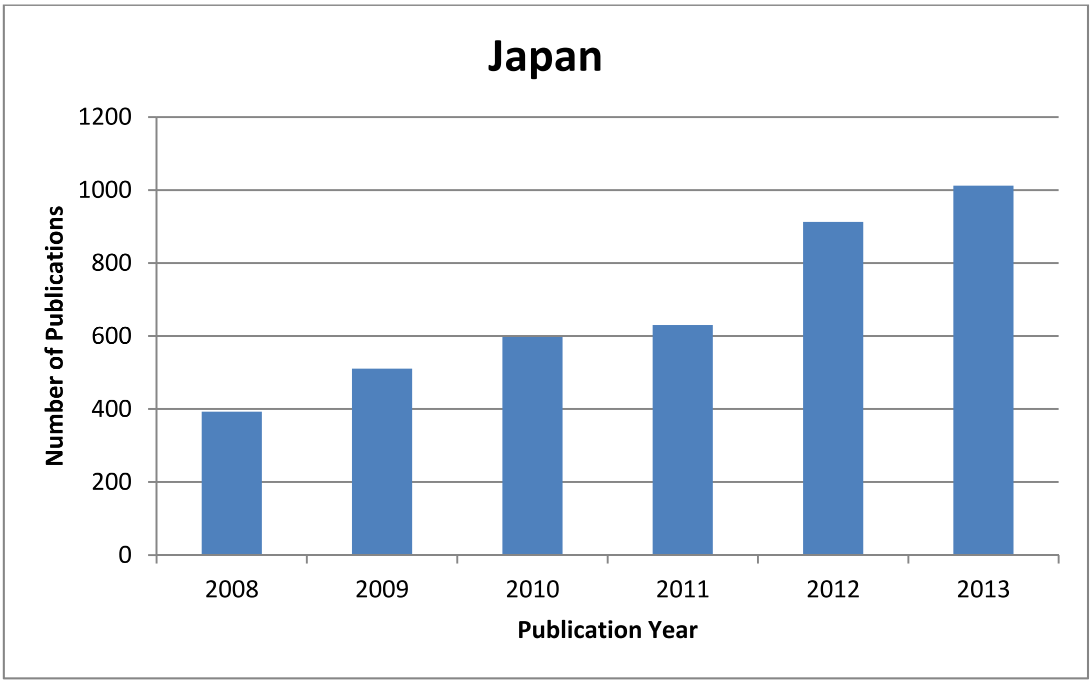

Figure 4: Temporal evolution of Japanese scientific articles

Despite the fast Asian growth in this sector, Europe is still the worldwide leader in total installed capacity, with 81.5 GW at the end of 2013 (EPIA, 2014). Germany is in the first position and the European Union makes R&D investments via the *Framework Programme*, in which industry professionals work together with researchers in the development and application of novel technologies, including solar PV.

The *6th Framework Programme* (FP6), carried out from 2002 to 2006, invested 107.5 million euros to support PV energy researches (European Commission, 2008). The FP7 followed from 2007 to 2013, resulting in new 213 new projects in this period (European Commission, 2013).

In Europe, other additional incentives foster the use of solar PV. According to Rüther *et al*. (2008), the German policies for renewable energy resources are considered the most successful. The growth of the German market is directly related to the introduction of the Renewable Energy Sources Act in 2000. This law created a *feed-in tariff* for electricity generated via solar PV energy for the 20 subsequent years. The electric system operators have to buy and pay a premium tariff for this kind of energy.

According to the International Energy Agency (IEA, 2012), 32% of Spain's electrical demand came from renewable sources, being 3.1% from solar PV. However, in January 2012, a government regulation cancelled the premium rates, resulting in a reduction in the growth of this market in 2013. In the United Kingdom, the development of this energy market also occurred after the *feed-in-tariff* establishment in 2010.

RESULTS AND ANALYSIS OF THE PATENT DOCUMENTS

According to the adopted methodology for the patent documents, 51,349 patent applications were retrieved. The temporal evolution, considering the priority year of the patent registrations, is shown in Figure 5.

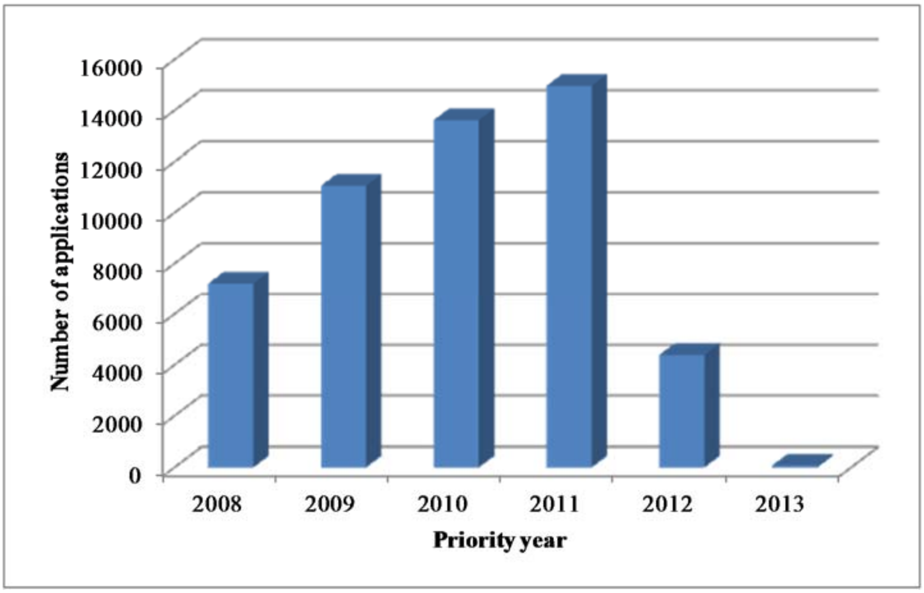

Figure 5: Temporal evolution of patent applications

The data from 2012 and 2013 aren't available yet due to an 18-month secrecy period and the extra time needed to include the documents in the patent database, which, in some cases, can take six months. Therefore, excluding the last two years, the behavior for the patent applications is similar to that of scientific articles, a steady growing profile. Moreover, as discussed in the introduction of this work, commercial application is also growing.

Because the period of analysis is very short, theoretical considerations about technology development models are impaired. Long-term analysis of the development of science-based technology can lead to a double-boom cycle of technology, where the first boom is associated to a *science-push* and the second to *market-pull* stimuli, with feedback loops (Irvine & Martin, 1984; Schmoch, 2007). Therefore, at the beginning, a wave of scientific publications followed by a wave of patent applications can be expected, fostering subsequent market diffusion. On the other hand, there are many case studies of technology development where these sequential activities are not present, supporting an "interaction and concomitant model" (Schmoch, 2007). As the articles, patents and commercial applications are steadily growing, this monitoring technology suggests that PV solar development seems to be more adherent to this last option. Anyway, this short-term survey allows some speculations, but no conclusions can be drawn.

Another important aspect that may be observed is where the technology is generated. The Priority Country, where the first patent file generally occurs, was used as an indicator, because applicants usually hold the first registration in their country of origin. The list of countries that applied for 50 or more patents is shown in Figure 6.

A strong Asian leadership is displayed in this plot. In 2013, Asia showed fast development in PV energy, and Europe showed a lower drive, going in the opposite direction. The total installed capacity in China and Asia Pacific, in 2012, was 8.1 GW, while in Europe 17.7 GW were installed. In 2013, the figures were 21.6 GW and 11 GW, respectively (EPIA, 2014).

The plot of the temporal evolution of the patent applications for the top five leaders is also detailed in Figure 6, which clearly presents a growth in the number of applications in China and Japan, whereas in the USA and in Germany the numbers remain stable.

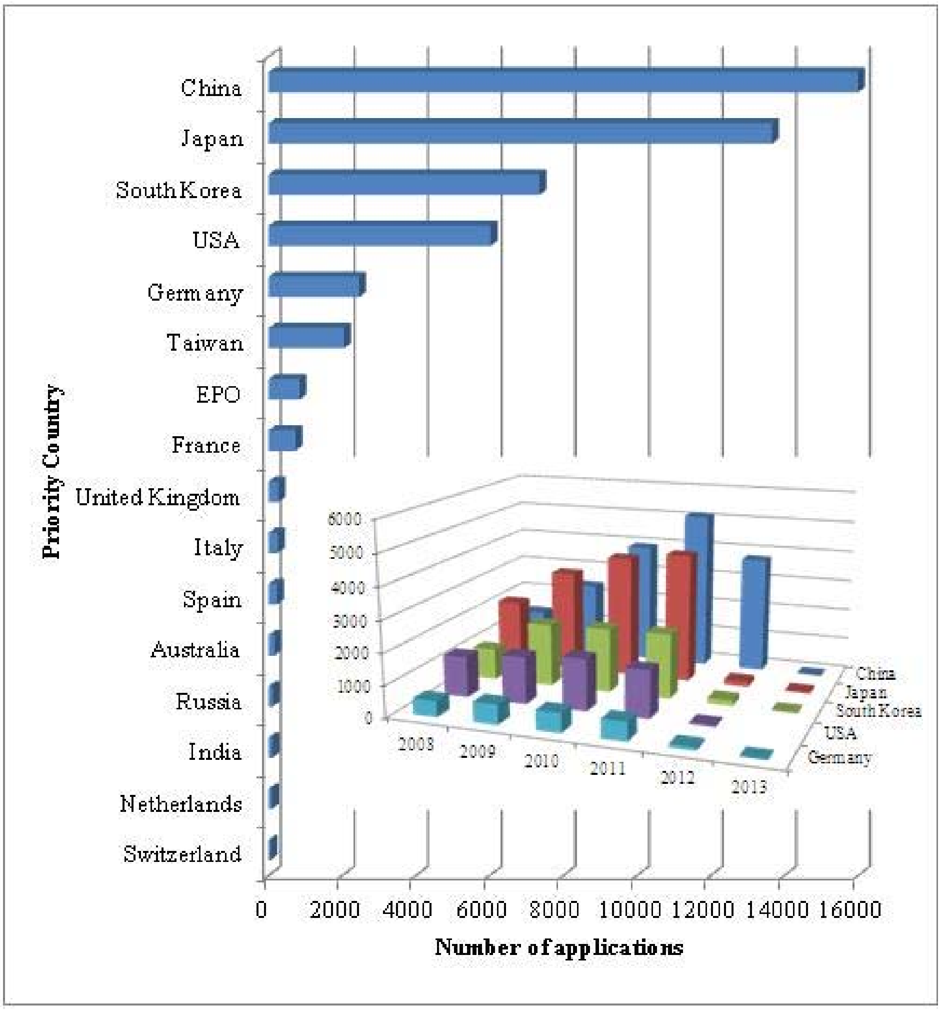

Figure 6: Ranking of the Priority Countries of patent applications, In detail: the temporal distribution for the top five leaders

Furthermore, an analysis that allows for cross-country comparisons by weighing the number of patents against the country population and economic activity was conducted. For these analyses, the total resident population and the gross domestic product (GDP) of each country over the period 2008-2011 were considered.

The total of priority applications of a country in each year (2008-2011) was divided by its population, and the average was calculated. The result is shown in Table 2.

Table 2: Number of priority applications per million inhabitants

Country	Priority Applications per million population
South Korea	36.6
Japan	26.4
Germany	7.09
USA	4.79
China	2.33

Using the same method, the priority application per GDP ratio was calculated, and the results are displayed in Table 3.

Table 3: Priority Applications per GDP

Country	Priority Applications per GDP
South Korea	1.77
Japan	0.67
China	0.64
Germany	0.17
USA	0.10

The tables above show that there is an inversion of order when these parameters are considered. In both analyses, South Korea is the leading country; however, it is in third position when the total number of priority applications is considered. Japan appears in second position for all parameters (number of priority applications, priority application per million population and priority applications per GDP). Due to its large population, China drops from the first place, in relation to number of patents, to the last position in Table 2, which shows the number of patents per capita.

Japan's outstanding position is explained by the Japanese government's introduction of a premium fare - *feed-in tariff*, in June 2012, which led to a significant increase in the number of installations of PV systems. Japan hopes to achieve 63 GW of installed capacity by 2030 (NREL, 2013). Additionally, with the vigorous growth observed in this sector in recent years, it is expected that the global PV capacity reaches 600 GWp by 2030, as laid down by the International Energy Agency (Pralon, 2013).

On the other hand, PV technology development effort is poor in Brazil. Only nineteen patent applications and 376 technical articles were retrieved, which is a minor set of documents when compared to the leading countries. Although Brazil has the largest quartz reservoir in the world, which is the raw material for silicon production, this product isn't domestically upgraded. According to Dr. W. Suemitsu, Professor at the Federal University of Rio de Janeiro, Brazil imports purified silicon, which impairs the competitiveness of the PV panel manufacturing in this country. However, the Brazilian government is interested in developing solar energy and has funded some R&D projects. The National Electric Power Agency of Brazil – ANEEL issued a call for projects in this area of knowledge, which resulted in eighteen new projects. Moreover, an Energy Innovation Program (Plano Inova Energia) was launched in April 2013 to support the Brazilian companies that have a position in the production chain of alternative renewable energies, including solar PV.

MAIN PLAYERS AND PARTNERSHIPS

In order to know the main players in PV technology development, the top twenty patent applicants are shown in

Table 4. This table presents the list of assignees, the country of origin, and the total of patent applications in the selected period.

Table 4: Top twenty patent applicants for solar PV energy

Main Applicants	Country	Number of Patent Applications
LG Electronics INC	South Korea	1,142
Sharp KK	Japan	913
Fuji Film CO LTD	Japan	531
Samsung Electronics CO LTD	South Korea	519
Mitsubishi Electric Corp	Japan	487
Sanyo Electric CO LTD	Japan	474
Kyocera Corp	Japan	410
Du Pont de Nemours&CO E I	USA	403
Konica Corp	Japan	398
Changzhou Trina Solar Energy CO LTD	China	322
Sumitomo Chem CO LTD	Japan	312
Applied Materials INC	USA	306
Chinese Academy of sciences	China	305
Matsushita Denki Sangyo KK	Japan	250
Dainippon Printing CO LTD	Japan	233
Sony Corp	Japan	224
Toppan Printing CO LTD	Japan	212
Hyundai Heavy IND CO LTD	South Korea	209
Ind Technology Res Inst	Taiwan	207
Toray Advanced Materials Korea Inc	Japan	193

Only two research institutes belong to this group, and the rest of the list is composed of enterprises. Asian companies are predominant, mostly Japanese. These top applicants are responsible for about 16% of the retrieved documents, showing that technology development isn't concentrated among few players. It is worth to mention that China, which leads the ranking of countries of priority, has only one company in the list, the Changzhou Trina Solar Energy Co Ltd. Another Chinese institution that also belongs to this top group is the Chinese Academy of Science, a governmental institution with many sites spread throughout China. There is a similar situation in the USA, which also has a large number of applications, although only two companies appear on the list. Thus, there is a high level of dispersion of the applicants in both countries.

The predominance of Japanese companies, eleven out of the top twenty, shows the efficiency of public policies, mainly the Renewable Energy Act, which is one of the most successful pieces of legislation on renewable energy promotion in Japan, as stated by Kuramochi (2015).

The large number of documents, either scientific articles or patent applications, shows high technology intensity in this area of knowledge. Therefore, a search was carried out to check the level of partnership between the top companies and/or institutions. Using the software *Vantage Point*®, a map was prepared, mapping the main applicants that have some kind of alliance, considering the patent assignees. Figure 7 shows the companies working in partnership, which are pinpointed with a red dot. The companies Kyocera, Konica, Dainippon

Printing, Toppan Printing Co Ltd, Hyundai Heavy, Toray Advanced Materials Korea Inc, and Industrial Technology Research Institute from Taiwan are not present in this map, due to no hint of partnership in their patent documents.

Of the top twenty applicants, thirteen had some kind of partnership. As mentioned before, most of them are Asian companies and the number of patents in which intellectual property was shared is very low. For instance, Sanyo Electric has 474 applications, in two of them the company formed a partnership with Japanese company Ulvac, and it has three other shared applications with another Japanese entity. That is, Sanyo Electric has five shared applications, which represents about 1% of the total. Another example is Dupont, which has 403 applications and only one partnership with North Carolina State University, representing 0.25%.

Samsung and Sumitomo are the leaders in pairing up with universities and research institutes, with twenty-one and fifteen shared patents, respectively. This corresponds to less than 5% of the total of patent applications for each company. This shows the level of partnership in the solar PV technology development is irrelevant, which seems to be unusual in science-based technology development.

Partnership is a trend in high-tech businesses, stimulating open innovations whose concepts are based on the theory that a company doesn't need to possess all expertise for the development of a new product/process/technology. Some benefits of partnerships are the shared risk related to R&D, reduced cost of conducting R&D, and joint complimentary skills of the involved partners (Chesbrough *et al.*, 2005). However, partnerships present some drawbacks, such as lost of competitive advantage, profit sharing, and the risk of disagreements and friction between partners and management.

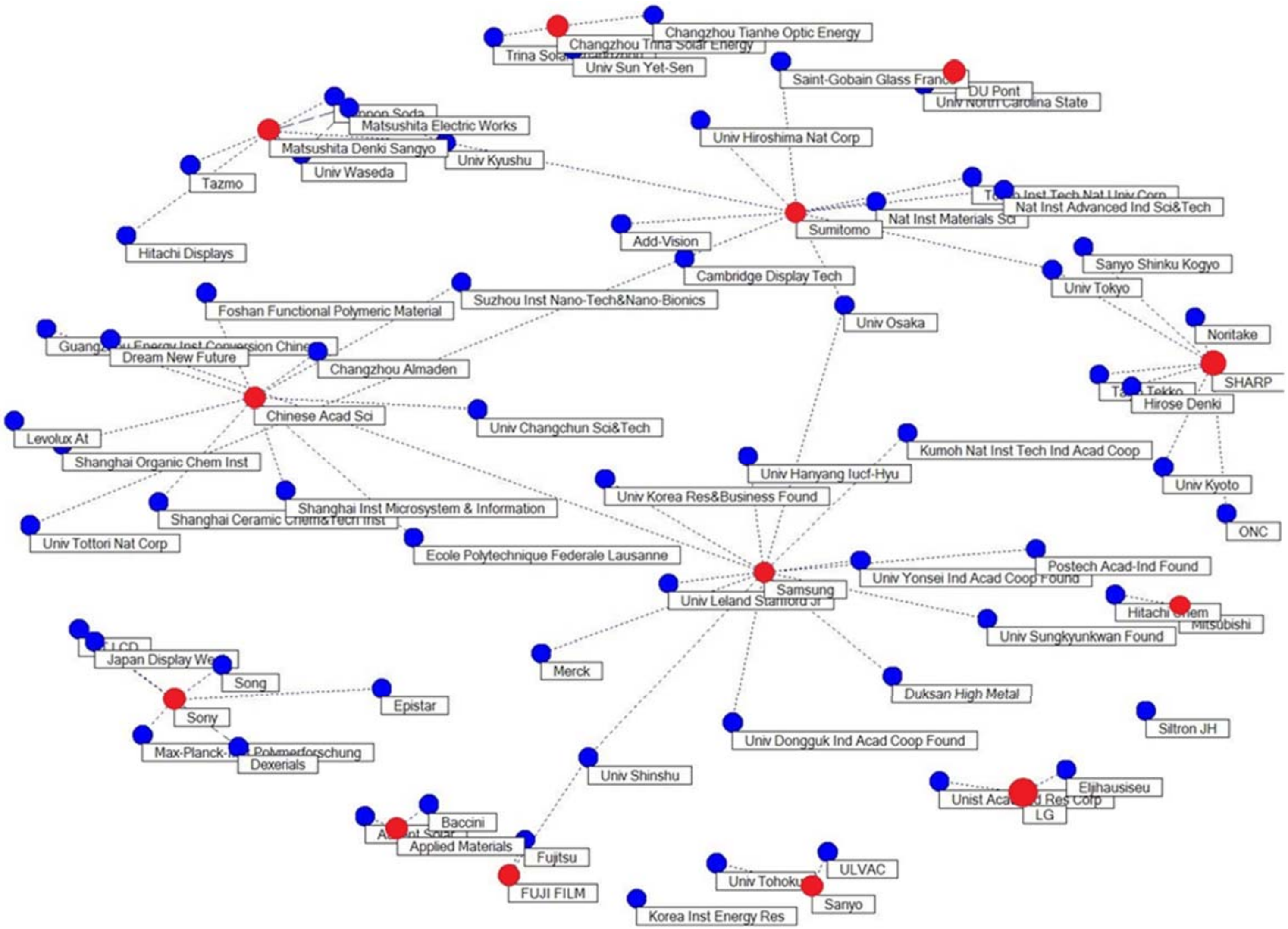

Figure 7: Map of the top applicants and their cited partnership in the patent documents

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PATENT CATEGORIES

Due to the large number of patent applications, it was impracticable to read each one for a qualitative classification. Consequently, it was decided to establish categories based on the Derwent Manual Code. In order to perform this classification, the criteria described in Table 5 were adopted.

Table 5: Patent Categories based on Codes and areas of knowledge

Category	Subdivision	Derwent Manual Codes
Film	Tandem	U12-A02A4C (Multifunction Tandem Solar Cells)
	Covering Layer	U12-A02A4D (Covering Layers For Solar Cells)
	Dye	U12-A02A8 (Dye Sensitized Solar Cells)
Semiconductor		X15-A02F (Organic Solar Cell)
		U12-A02A2D (Solar Cells With Organic Materials)
		U12-A02A2 (Semiconductor Materials And Structures For Solar Cells)
		U12-A02A2A (Solar Cells With AII-BVI Compounds)
		U12-A02A2B (Solar Cell With AIII-BV Compounds)
		U12-A02A2C (Solar Cell With AIV Compounds)
		U12-A02A2E (Solar Cell With Chalcogenide/Chalcopyrite Compounds)
		U12-A02A2F (Solar Cell With Amorphous, Polycrystalline Semiconductor)
		U12-A02A2X (Semiconductor Materials For Solar Cells – Other)
Set of solar cells	Matrix	Keyword was used
	Module	Keyword was used
	Assembly of cells	X15-A02B (Assemblies of Cells)
		U12-A02A5 (Assemblies of Solar Cells)
	Panel	X15-A02C (Solar / Photovoltaic Panel Details)
		X15-A02X (Other Solar / Photovoltaic Panels / Cells Details)
Structure	Joint/Junction	Keyword was used
	Packing	U12-A02A4E (Packaging Aspects For Solar Cells)
	Layer	Key word was used
	Electrode	U12-A02A4A (Solar Cell Electrodes)
	Substrate	U12-A02A4B (Solar Cell Substrate Details)
	Circuit Arrangement	U12-A02A7 (Power Transfer, Circuity Arrangements For Solar Cells)
	Devices	L04-E05D (Photovoltaic Devices, Photoelectric Cells)
Nanotechnology		Keyword was used
Tracking		Keyword was used

Besides the codes in the table above, additional generic codes such as X15-A02 (Direct Conversion Photovoltaic Panel Details; Solar/Photovoltaic Cells Details), X15-A02A (Single Cells) and U12-A02A1 (Single Solar Cell) were used and screened using pertinent keywords by the *Vantage Point*® Software.

This classification makes it easy to identify the focus of the technology development. The application intensity of the distinct parts/devices of the PV technology is shown in Figure 8.

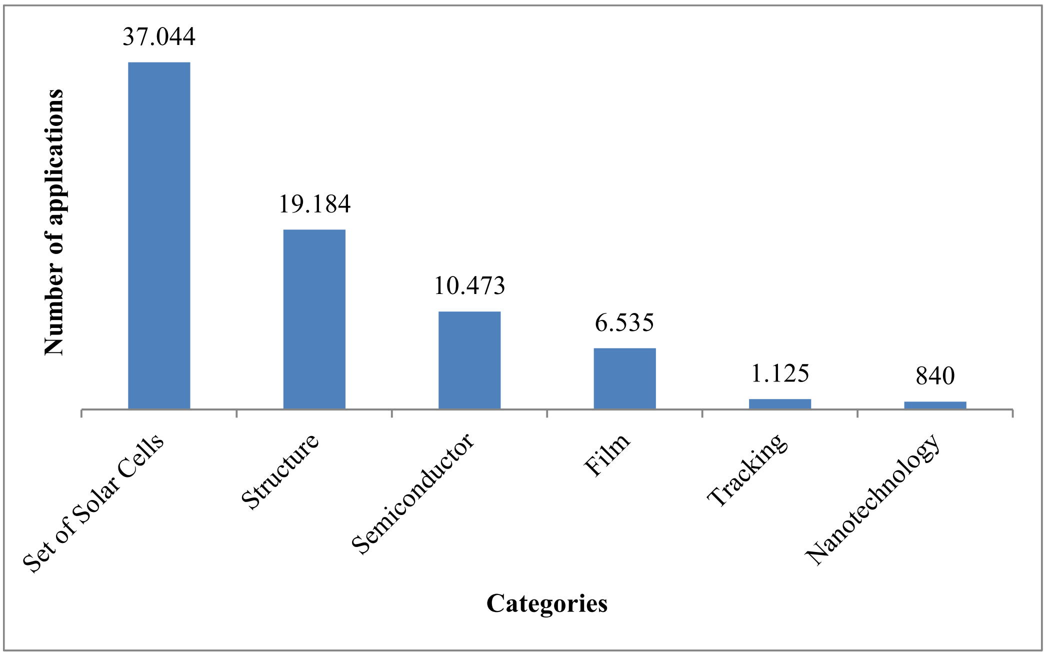

Figure 8: Number of patents per category

It is worth mentioning that the major categories of patent application for PV technology are set of solar cells, structure, and semiconductor, having the first one a clear leading position.

CONCLUSION

The search output of the scientific articles and patent applications showed the great interest in the development of solar PV energy technology over the period analyzed (2008-2012). The USA and China lead and have a prominent number of academic publications. Besides these countries, Germany, Japan, and South Korea also have a relevant number of papers. In total, 55,755 scientific articles were retrieved, and temporal evolution shows an increase in publications over time.

In relation to patent applications, the total figure was 51,349 documents. The Asian countries stood out, being China, Japan, South Korea and Taiwan in the foreground. The USA and Germany complete this leading group, showing a similar result to that obtained by scientific papers. China and Japan, which have the highest number of applications, 16,474 and 13,670 respectively, presented a much higher increase in the temporal evolution curve than the USA and Germany. Moreover, the installed PV generation capacity in China increased substantially in 2013, indicating that the development and application core of this type of energy is moving towards Asia. At the beginning, Europe led the R&D activities and installed capacity of PV energy due to governmental incentive and the creation of a *feed-in tariff*; however, the trend now is to have China, Japan and other Asian countries in the front end.

Two other analyses using demographic and economic data of the main countries were made. In these, it was observed a different order in the leading country. However, as mentioned by the WIPO, the differences in patent filings per population or GDP do not necessarily mean that one country is more inventive or more efficient in its allocation of resources than the other.

The break down into categories carried out using the patent documents showed the most outstanding technological development areas: Set of Solar Cells and Structure, with 37,044 and 19,184 documents respectively.

In Brazil, the number of scientific articles is much higher than the number of patent applications, showing that technology development is still in embryonic phase. The number of documents in both groups was irrelevant, in spite of the favorable potential for the application of this technology, considering the country's large geographic area in the tropical zone and its high quartz reserves.

As lessons learned for the technological monitoring, though the search was based on patent applications and scientific papers, it is important to survey the technological programs supported by government funding and to track the established incentive policies, in order to better understand the high technology intensity in this area of knowledge.

In addition, as usual, the search strategy for patents based on a combination of Derwent Manual Codes showed a greater volume of relevant and pertinent documents when compared to the strategy of using a set of keywords found in the title and/or summary of the patent document.

ACKNOWLEDGEMENTS

The authors thank CAPES (Brazilian Federal Agency for Support and Evaluation of Graduate Education) for granting access to the Derwent Innovation Index and Web of Science databases, available at the CAPES Journal Portal (http://www.periodicos.capes.gov.br/).

The authors also appreciate the pertinent comments and suggestions made by the Reviewer of the IAMOT Conference, who contributed to the enrichment and greater clarity of this paper.

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