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Photovoltaic technologies: Mapping from patent analysis

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ABSTRACT

The objective of this article is to identify the technological development of photovoltaic cells by the analysis of patents. The Derwent Innovations Index (DII) database of Thomson Derwent was used for this research. 22,682 patents were obtained. The results indicate that 1) the number of patents deposited on photovoltaic cells grows every year, 2) the main depositor countries are the United States, China, Japan, Germany and South Korea, 3) American and Japanese organizations stand out with the highest number of patent registrations, 4) the main areas of knowledge were Engineering, Instruments and Instrumentation, Energy and Fuels, Chemistry and Polymer Science, 5) the patents on photovoltaic cells are concentrated in the area of semiconductors for the conversion of solar radiation into electric energy, in the area of generators for the direct conversion of light energy into electric energy and in the area of solar panels adapted for roof structures and 6) there is a prominence of deposited patents for polymer-based photovoltaic cell technologies, carbon nanostructures, III-V compounds, cadmium telluride and amorphous silicon cells.

1. Introduction

The use of traditional fossil fuels to generate electric energy causes serious environmental problems, such as climate change, global warming, air pollution, and acid rain, among others. On the other hand, the consumption of electric energy on the planet increases using due to modern society's increasingly use of equipment and products that run on electricity. In this perspective the development of renewable energy technologies is necessary to obtain competitive prices to compete with traditional sources of energy that generate environmental pollution [1–6].

To address these problems, some nations have taken challenging measures. The United States, for example, announced its “Advanced Energy Initiative” in 2006 and outlined a daring goal to reduce imports of Middle Eastern oil by 75% by the year 2025 through the development of new and renewable energy sources. The South Korean Government, in turn, has established “The 2nd National Plan for Energy Technology Development” to improve its global competitiveness in energy technology. This plan aims to develop new and renewable energy technologies and improve energy efficiency by doubling energy-related research and development investments in the country by 2020. In addition, Japan and China have also established national energy

Development of new and renewable energy technologies to reduce their dependence on fossil fuels and to foster a strategic green growth industry [7].

Photovoltaic technology has developed rapidly over the last thirty years. The main activities of photovoltaic patents began in the late 1950s and the main photovoltaic patent assignees at that time were involved in the space business [8,9].

Patent data has been widely used in technology assessment and forecasting [10–13]. The patent is a right granted to the researcher and is an outlet for scientific and technological development, revealing what organizations consider worth protecting. A collection of patents in a particular discipline may represent part of the accumulated knowledge in science and technology within that discipline. The growth of the number of patents of a given technology provides a good indication of its state of development [8]. However, care must be taken in using the quantity of patents to draw conclusions, since this quantity may have no relation to the quality and strength of the patent [14].

For alternative technologies, such as photovoltaics, research and development analysis is important for the observation and understanding of technologies in the market. Photovoltaic cell patent registrations are a valuable data set in the analysis and diffusion of PV

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technology and R&D activities. The dynamics of PV R&D activity is considered high, documented in a large increase in PV patent documents [9].

Considering the development of technologies in photovoltaic cells and the increase on production of electric energy by the solar source [3], a question arises is: how is the technological development of photovoltaic cells from the analysis of patent registration? The aim of this paper is to analyse patents related to the technologies of photovoltaic cells that were deposited between the years of 2004–2013. In this way, this paper contributes to the monitoring of photovoltaic cell technologies.

The article is organized in the following manner: Section 2 contains the literature review on photovoltaic cells technologies and patent analysis. Section 3 presents the methods as well as the detailed research procedure. Section 4 includes the analysis of the photovoltaic cells patents. Finally, the last section presents the conclusions, recommendations and suggestion for future research.

2. Literature review

The literature review covered the topics photovoltaic cell technologies and patent studies and analysis.

2.1. Photovoltaic cell technologies

The literature about photovoltaic solar cell technology considers three generations. Table 1 presents the main photovoltaic technologies: first generation (fully commercial) systems that use crystalline silicon technology in both their simple crystalline form and polycrystalline; second generation systems that are based on photovoltaic thin and generally include three major families: amorphous silicon, cadmium telluride and indium copper selenide, indium and gallium-diselenide; and the third generation ones that include organic photovoltaic cell technologies that are still under demonstration or have not yet been widely marketed, as well as new concepts in development.

Studies conclude that to increase PV participation in the renewable energy market it is necessary to raise awareness about the benefits (social, economic and environmental); Increase research and development of new technologies (to obtain cheaper and more efficient cells); Implement public policies and programs that encourage PV generation; More qualified professionals for this market. The photovoltaic industry needs to improve conditions for a reliable policy framework to ensure a return on investment, innovation and continuous research [41].

2.2. Patents as a source of technological information

Technological innovation is a fundamental condition for the success of the process related to productive systems and many companies invest in the development of technologies. However, in order to guide research activities, save time and avoid unnecessary expenses, the search for technological information available on patent bases and in specialized literature should be consulted before starting new projects [42,43].

Identifying product opportunities using patent analysis is important because it facilitates the creative process of generating new products that product developers do not tend to intuitively consider. Being able to forecast products and services that can lead the future allows for greater competition between rival companies. Providing promising technology through patent analysis is a relevant opportunity for the management and decision-making of companies and countries [44,45].

The future success of a particular technology has to be predicted before the investment decision. In this way, Altuntas, Dereli, and Kusiak (2015) propose a new method for predicting technological success based on patent data that takes into account in four aspects: technology life cycle, diffusion speed, patent strength and potential of expansion [46]. As patents result from the company's investments in basic

research and applied development, patent data can be considered as a good representative of the company's genuine inventive activity [47].

The patent is a temporary title to an invention or utility model, granted by the State, by virtue of law, which gives the owner or his successors the right to prevent third parties, without their consent, from producing, using, place on sale, sell or import the product object of its patent and/or process or product obtained directly by process patented by it [43]. The invention is characterized by the requirements of novelty, inventive step, industrial application and descriptive sufficiency, its validity is 20 years from the date of filing. The utility model is the object of practical use, or part of it, susceptible to industrial application, which presents a new form or arrangement, involving an inventive act, which results in a functional improvement in its use or in its manufacture. It is valid for 15 years from the date of deposit [42,48]. The patent is valid only in the countries where it was requested and granted its protection. Each country is sovereign to grant or not the patent independently of the decision in other countries on corresponding patent applications [42,43].

Patent documentation is the most comprehensive of all research sources. Studies show that 70% of the technological information contained in these documents is not available in any other type of information source. According to the World Intellectual Property Organization (WIPO), the number of patent applications has grown to around 1.5 million each year, resulting in more than 500,000 patents granted. Companies in the United States, Japan and Europe increasingly use this instrument as a strategic input [42,43].

Patents promote the dissemination of knowledge and innovation. Therefore, patent documents are a rich source of technological and commercial information. They record the nature of the invention, the direction of technological development and R&D activities [49]. Besides that, the patent registers allow one to analyse the invention as to the novelty aspect: i) detect /; Detect/prevent patent infringement, ii) research technological advances in ones area, iii) identify opportunities for acquisitions and licensing, iv) avoid duplication of R&D initiatives, v) monitor competition, vi) determine the extent of protection of the invention, vii) find potential loopholes in the market, viii) identify the specialists or inventors for competitive intelligence and recruitment, and ix) to search English language equivalents to analyse patent documents published in a foreign language [50].

Patent documents, as well as patent applications, are sources of information and technological knowledge, and can be used by any company, university, research institution, government body and especially by researchers who carry out technological prospecting. Access to these documents occurs through the public or private patent databases [48]. Table 2 presents the main bases that can be consulted.

The most frequent analyses that can be done from the patents are [51]:

- Regarding the history: in order to evaluate the behaviour of the number of patent document deposits over time, monitoring allows us to deduce the interest or not in the development of the technology of photovoltaic cells;
- The history of deposits by a depositor country: this analysis aims to illustrate the evolution of deposits of patent documents in different countries over time in order to identify which countries are active in the research and development of this technology. To do so, the country of first filing of the patent is used, which in general is the owner of the technology;
- The depositors: to identify both the companies and/or institutions that deposit the patent documents over time, and therefore, would be the leaders in the development of such technology;
- The areas of knowledge: in order to identify the most prominent areas among the deposited patent documents;
- The International Patent Classification: to order the patent documents, in order to facilitate access to the technological information contained therein.

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