Contemporary Engineering Sciences, Vol. 10, 2017, no. 19, 911 - 920
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2017.7887

Solar Energy Research: A Scientometric Study in the Period 1956-2015

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Abstract

Energy is a fundamental component in sustainability, the access and use of this resource is related with economic growth, social improvements and environmental impacts. In this sense, solar energy is the main source of renewable energy nowadays, and its development is the driven force for others kind of Green energies, with the purpose to face global warming and climate change. This study presents the results of scientometric techniques application into the evaluation solar energy research evolution, using Scopus as data source for the period 1956-2015, finding and analyzing 40.585 documents. This scientometric study allowed to identify, not only the stages of development in solar energy research, furthermore to establish the structure, main subjects, institutions, and stakeholders involved in this research. In addition, the application of scientometric analysis allowed to establish the trending topics in the research, being this study a framework to develop new research lines.

Keywords: Solar Energy, Scientometric, Research Trendings, Scopus

1 Introduction

Energy is a fundamental factor in development of societies, from an economic point of view, its use is closely related to the industrialization stage, becoming an input for production and a relevant variable for the observation of consumption patterns in society [1] At this point, the energy demand changes according to the patterns of economic growth, production, and lifestyle changes related to the different

levels of development in communities [2], where is evidenced the tendency to use more energy per unit of economic output and far more energy per capita for the more advanced and industrialized societies than poorer ones, especially those in a preindustrial stage [3]. In this sense, solar radiation is used in thermal and photovoltaics energy conversion devices, being actually the most efficient source of renewable energy. Therefore, in order to develop a new research line, it is necessary to identify and analyze the structure, patterns, and trends in this global research.

In this paper, was used a study technique called "Scientometry" where, the use of bibliographic data, allows to develop a prospective analysis of the growth rate of researchers and institutions in this field of study. These results are important to establish a theoretical framework in order to take decisions about the future researches, important for the conformation of new research groups.

The main contribution of this paper is to describe the different stages in the research history of solar energy, allowing to identify points of interest such as, the influence of oil crisis and environmental concerns into the evolution of the field. Moreover, the evaluation of most influential authors and institutions, which is an important issue to identify future research partners. Finally, the analysis of subjects and areas, are the theoretical guide to find out where the research is moving and the current trending.

2 Methodology

Stage 1 - Problem delimitation: the application of scientometric analysis in this study leads to identify the main trends and applications of "solar" as part of energy studies and determine general structure and dimensions involved in the research of solar energy applications. The application of scientometric analysis to the field of interest (in this case: solar energy research) will provide knowledge about the structure and trends in the domain, according to the main concerns of the study.

Stage 2 - Search parameters: in order to conduct a scientometric study of solar research related to energy, the search was carried out using Scopus as reference source due to its wide range of publications covered [4].

In order to record the most accurate information, in this stage the main activity was the design and test of the research algorithm which allowed to get the greatest quantity of documents related to the study. The delimitation of the search parameters includes: Time delimitation: for the study of structure and evolution, time delimitation was not applied, however, in the 3rd stage, for the maps application (see stage 3) the time delimitation was set to the last 5 years of production.

Source limitation: The search was limited to only research papers, in order to cover all the publications related to the field of study. In general, the search must include the keyword "solar", there was no limitation about the sources (Journals) but the main concern was that all the papers must be related to Energy applications.

With these criteria, the search equation was obtained:
(TITLE-ABS-KEY(Solar) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO(SUBJAREA,"ENER"))) (Equation 1)

Applied to this search, a total of 40.585 papers were obtained for analysis.

Stage 3 - Scientometric study: includes two phases, the Scientometric study to identify and co-word analysis to evaluate the structure and trends of the current research using statistical tools [5]. For the first phase, all the papers obtained were analyzed to acquire a complete overview. The following variables were studied publication along the time, the price curve (Maturity of the field), the geographic, institutional and author's profiles. Then, statistical analysis was applied to get a graphical view (trends map) of the structure of the research [5], [6].

3 Results and discussion

The number of publications and the production patterns along the time show the evolution and current status of the scientific activity in a determined field [7], besides allow to identify the increasing status of a research field and the maturity level of the same, according to the Price´s law. In this case, the evolution of papers, with the keyword "solar" included in the field of energy research is shown in figure 1. Starting since 1956, where two papers were found, until 2013 where 4500 papers were found. Thus, it is possible to observe at least three stages in this evolution as follow:

From 1956 to 1975: there is a linear evolution in the research trend. In the 70's, this is explained by the impacts of fossil fuels on the environment, which encouraged the interest of science into the search for new and renewable energy sources [8]. In this period, is important to notice the work developed by Vavilov [9] was the first document found, and also highly cited authors as Tabor [10] with the arrangement of mirrors for solar collectors, Telkes [11] with the design of solar cooking ovens, Bliss [12] with technical parameters for the design of solar collectors, and other authors, showing during this period a growing interest of finding technological solutions for the use of solar energy with emphasis, in this early stage, mainly in solar concentrated power.

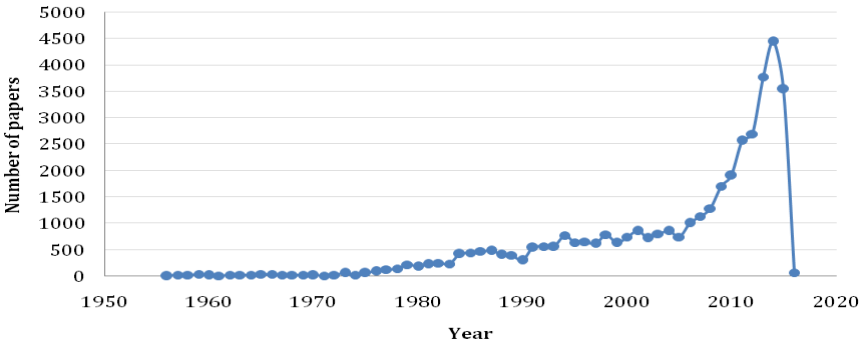

Fig. 1 Number of publications along the time since 1956 until 2015

From 1975 to 2005: there is a second stage of growing in the field, which presents a linear trend that shows a normal variation in the behavior of the curve. This trend is also part of the first stage in the Price´s law analysis, where there is a constant increasing in the knowledge and capacity of creation in the field of study. In this period, the most cited works correspond to Contreras et al [13] with the design of solar cells and the evaluation of its performance, Brabec [14] with the analysis of organic photovoltaic technology, and Granqvist [15] with a review of tungsten oxide films. The analysis of the production in this period also shows that the trend is clearly the growing interest in materials, design and efficiency evaluation of photovoltaic technologies. From 2005 to 2015: there is an exponential growth in the number of publications. The growing rate of technology is due to the maturity state of the same, the cost reduction in materials, and the government support for electricity production based on renewable energies [16]. Solar concentrated power and photovoltaic applications research are increasing during this period.

For this research, a total of 40.585 papers were found, the first one found was "Solar batteries on the direct transformation of radiant energy into electrical energy by means of photo-elements" by Vavilov in 1956 [16]. According to the impact factor, the number of citations of a publication shows how many times has been referenced to discuss the findings of a specific problem in the research field, for instance the work of Esram & Chapman [18] which was the most referenced during the period consulted and highlights the techniques for tracking photovoltaic systems to get a maximum performance. During the course of the last five years, the search allowed to find a total of 17.886 papers emphasized on solar cells, such as the works of [17] - [19] which concentrates more than the 10% of the citations in the papers analyzed.

Tables 1 and 2 show the countries and institutions leaders, which allows complementing the trending study with the identification of the main authors in the research of solar energy applications. United States and China published approximately 27% of the production, where the first 10 countries represent the 62,87% of the number of the publications.

Table 1. Percentage of contribution of papers published by countries from 1956 to 2015.

Institutionally, the top ten institutions represent the 9,81% of the total production of papers; is noticeable how institutions such as the Indian Institute of Technology Delhi with 749 publications concentrates approximately 20% of the top ten institutions, besides the 26% of the national production of India, which is the third country in the world with most papers published. The rest of universities, also show a correlation between the territorial and institutional leadership in the top ten countries as shown in Table 2.

Table 2. Top ten institutions.

AFFILIATION,	***No.Papers***
Indian Institute of Technology Delhi	749
National Renewable Energy Laboratory	478
University of New South Wales UNSW Australia	429
Uzbekistan Academy of Sciences	425
Fraunhofer-Institut fur Solare Energiesysteme	395
Shanghai Jiaotong University	322
Chinese Academy of Sciences	303
National Taiwan University	283
Tsinghua University	265
University of Science and Technology of China	239

The areas of study represent that knowledge and research disciplines are involved in the evolution of the field, the search was delimited to documents with the word "Energy" included in the search field, the distribution of research areas excluding the word "Energy" are shown in figure 2.

As shown in figure 2, materials science rises up to 38% of the research interest, including documents that explore mainly the design and evaluation of solar cells,

showing also that photovoltaic applications concentrate the interest of the worldwide researchers, these results are associated to the 24% of documents in engineering sciences, showing that solar cells construction is a problem directly related to the development of new technologies.

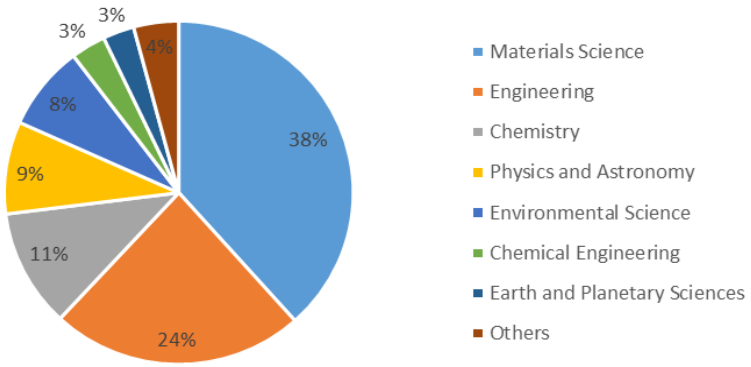

Fig. 2 Distribution of research areas

A co-word map made by applying a correspondence analysis using Ntsys software is shown in figure 3. In this map, the research trends are shown as a cloud of words, where close words represent a trend, a correlation of ideas and concepts involved in the development of technologies for solar applications.

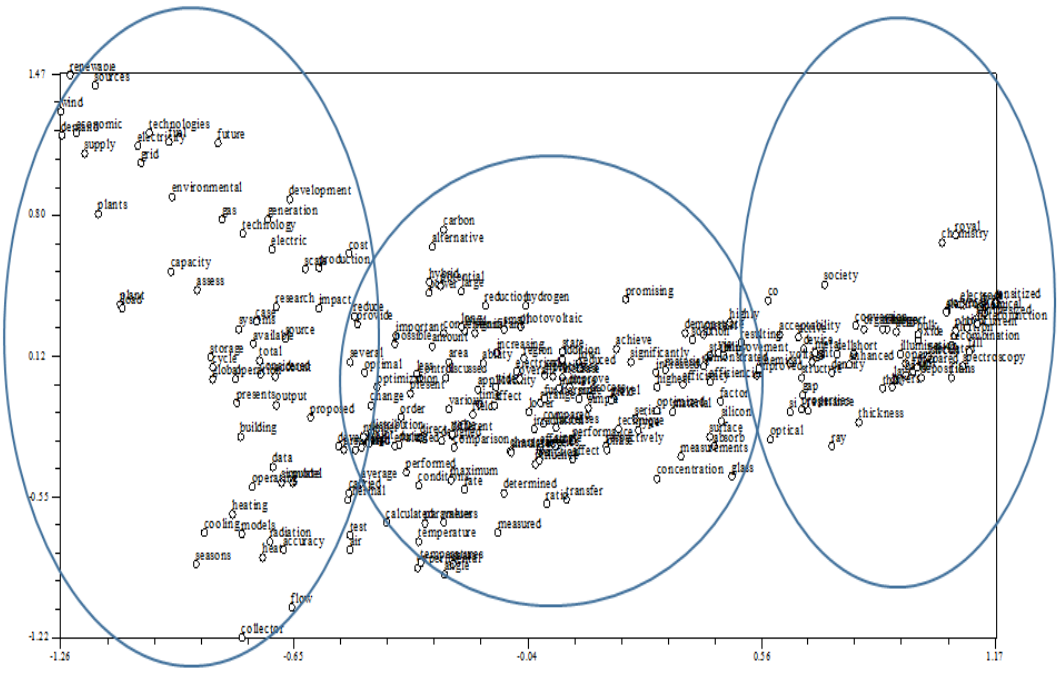

Fig. 3 Correspondence analysis map

As shown in figure 3, there are at least three different trends. The first group composed by words such as: renewable, sources, economic, demand, grid, technologies, future, development, capacity, assess, generation, cost, production, reduce, carbon, outputs, and so on and so forth, show a general view of the objectives in research. The second group, with the largest quantity of words, is around hydrogen, photovoltaic, increase, comparison, performance, effect, and other words that show the objectives of research in the basic technology and applications of photovoltaic research. The third group shows concepts such as improvement, silicon, factor, conversion, thin, gap, spectroscopy, oxide, CO, measurement, performance and so forth, show a trend associated with researches focused on the technical design and evaluation of performance of solar technologies. However, these three trends are shown and analyzed only in a general way, due to the fact that the high concentration of concepts in the map. In order to overcome this problem, a second map was developed using Njoin analysis, so that the clusters of concepts that allow establishing a trend with more details, can be clearly identified. The resultant map is shown in figure 4. In order to generate this map, 200 words were analyzed (The most common words from 14645 documents) identifying three clusters, research oriented to improve the efficiency of solar technologies, with concepts such as cell efficiency, conversion, power, performance; consideration of technical and technological conditions in the development of solar technologies (Applicability, different systems, temperature, thermal, heat, water, conditions, compared, surface, area, cost, potential, effect, time, process, and so forth) an relation of technological elements for evaluation and study of technologies (model, data, radiation, development, experimental).

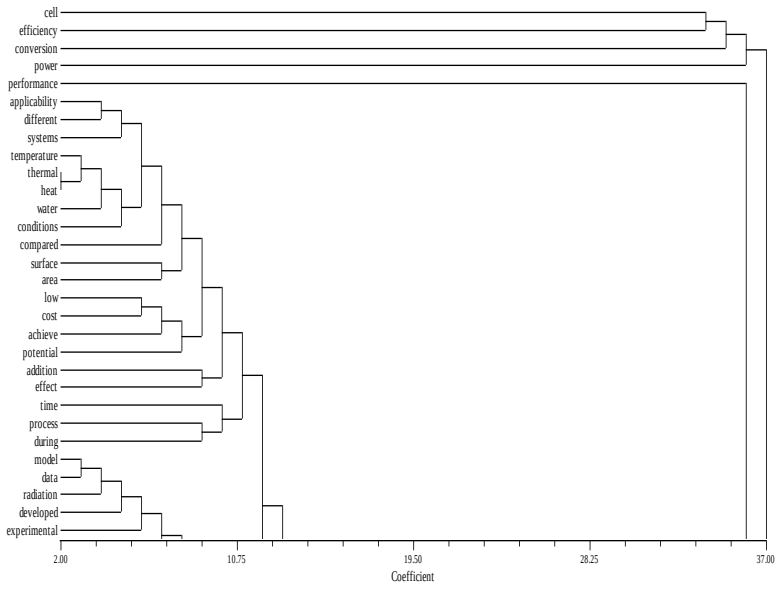

Fig. 4 Clusters map

4 Conclusions

The timeline of the study indicates that researches in solar energy have been evolving in at least three identified stages, and the evolutions is leaded by matters such as public concern of environmental issues, oil crisis and technological evolution. According to figure 1, solar energy research is a field in stages of maturity and growing, in areas where the applications include the search for problems solving as conversion efficiency, materials development, and technology application, among other topics as shown in figure 3.
Geographically, three leaders are identified as follows: USA, China and India, furthermore the institutions belonging to these countries are research leaders in this field, this represents a concentration of efforts in the research policy planning, which displays a strong relationship between geographical and institutional leadership. Even, when solar energy can be divided in two large group of applications (Photovoltaic and thermal applications) the analysis of documents obtained presents a high concentration of effort in the field of photovoltaic research which includes the study of cells, design, materials evaluation, efficiency study, and so on so forth.

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Received: September 8, 2017; Published: October 19, 2017