Renewable Energy 66 (2014) 696–706

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

A bibliographic analysis of recent solar energy literatures: The expansion and evolution of a research field

Huibin Du [a,b,*], Na Li [a], Marilyn A. Brown [c], Yuenuan Peng [d], Yong Shuai [e,**]

[a] College of Management and Economics, Tianjin University, Tianjin 300072, China
[b] Center for Energy and Environmental Policy research, Institute of Policy and Management, Chinese Academy of Science, Beijing 100190, China
[c] School of Public Policy, Georgia Institute of Technology, Atlanta, GA 30332, USA
[d] School of Environment and Energy, Shenzhen Graduate School of Peking University, Shenzhen 518055, China
[e] School of Energy Science and Engineering, Harbin Institute of Technology, Harbin 150001, China

ARTICLE INFO

Article history:
Received 2 July 2013
Accepted 2 January 2014
Available online 11 February 2014

Keywords:
Solar energy
Bibliometrics
Social network analysis
h-Index

ABSTRACT

This paper characterizes the solar energy literature from 1992 to 2011 using bibliometric techniques based on databases of the Science Citation Index and the Social Science Citation Index. Journal articles were the most frequently used document type representing 86.4% (6670) of the records. The pace of publishing in this field increased exponentially over these two decades, with the US accounting for the highest h-index (87) and the most publications (1273), followed by China and India. The US also plays a central role in the collaboration network among the 20 most productive countries, while China and India do not because of their more limited cross-national authorships. The Indian Institute of Technology was the organization with the most records (126), but it has few multinational co-authored articles. In contrast, the Paul Scherrer Institute in Switzerland is central to the collaboration network. The largest number of retrieved journal articles was in the area of energy applications (1059 articles) followed by light absorbing materials (983) and solar cells (420). Energy applications mainly address hydrogen, desalination, air conditioning, drying, heat pumps, biomass, and water splitting, while the light absorbing material mainly cover nano materials, TiO_2, semiconductors, thin films, phase change material and so on. This analysis not only identifies global hotspots in solar energy research, but may also influence researchers' selection of future studies and publications.

1. Introduction

The destabilization of the world's climate, driven by relentless emissions of greenhouse gases, has the potential to accelerate global warming and extreme weather events, exacerbate water and food shortages, damage valuable coastal property, advance the spread of infectious disease, and induce mass migration, potentially leading to a less prosperous and more insecure world [1]. While fossil fuels are being exhausted and the natural environment is deteriorating, the sustainable development of alternative energy resources has become a major concern of many nations.

Among various alternative new energy resources, solar energy is a completely renewable and abundant resource with rapidly declining conversion costs; it therefore is likely to be a popular option for generating electricity in coming years. According to its primary energy product, solar energy conversion methods can be classified into three categories: solar to electricity, solar to liquid fuels, and solar to thermal energy. With the development of science and technology, solar energy research and application have been receiving increasing attention throughout the world and is forecast to play a greater role in the energy mix in upcoming years as shown in Fig. 1.

Corresponding to the increasing recognition of the potential role for solar energy, the associated body of literature has also grown substantially. Thus, it is time to implement bibliometric analytical techniques to evaluate the growing body of literature on solar energy. The Bibliometric technique offers an important quantitative perspective to assessing the development and growth of research on strategic topics. It is a statistical method of bibliography counting to evaluate and quantify the growth of literature for a particular subject [3]. It is worth noting that bibliometrics is quantitative by nature, but is used to make pronouncements about qualitative features. In fact, this is the major feature of all sorts of bibliometric techniques to transform something intangible (scientific quality) into a

* Corresponding author. College of Management and Economics, Tianjin University, Tianjin 300072, China. Tel.: +86 22 27404446.
** Corresponding author. School of Energy Science and Engineering, Harbin Institute of Technology, Harbin 150001, China. Tel.: +86 451 86412308.
E-mail addresses: duhuibin@tju.edu.cn, maoguozhu@tju.edu.cn (H. Du), shuaiyong@hit.edu.cn (Y. Shuai).

0960-1481/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2014.01.018

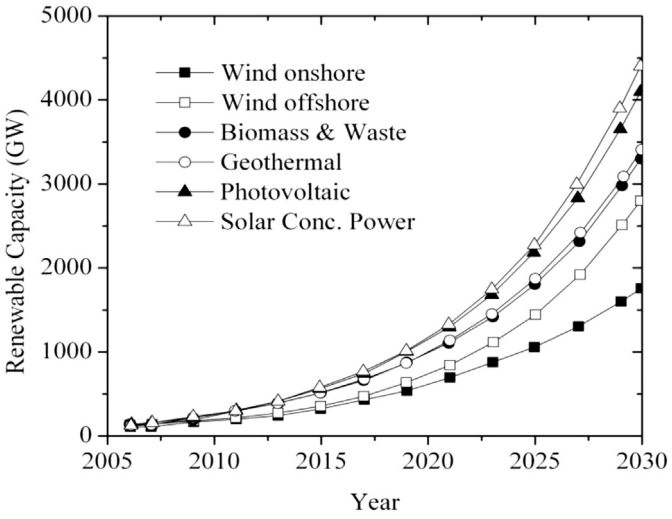

Fig. 1. Development of renewable electricity generating capacities in the world regions [2].

manageable entity. There are two advantages in implementing bibliometric analysis: (1) it provides an assessment of the research or the scientific production in a specific area over a period of time using indicators and the calculation of certain classical laws [4]; (2) it examines science as a knowledge-generating system. Many areas of science have tried to evaluate their evolution or growth by this method and, nowadays, the bibliometric technique has become an indispensable instrument for measuring scientific progress [5].

Originally, the bibliometric method has been applied in library and information sciences as the research methodology for citation analysis and content analysis; the conventional bibliometric method has also been widely applied in various fields by investigating the publication characteristics, such as countries, research organizations, journals, research fields, and citation habits [6–8]. However, in recent years, analyses of word distribution of paper titles, abstracts, and keywords in different periods have been used widely to get more refined information related to the research itself [9–11].

This study aims to investigate the characteristics of the solar energy literature from 1992 to 2011 and its implication using bibliometric techniques. This statistical method of bibliography analysis evaluates and quantifies the growth of publications addressing a particular subject, and examines publication characteristics consisting of countries, research institutes and fields, journals, authors, citation habits and author keywords. Furthermore, some priority research directions with high potential are identified to advance dramatically solar energy conversion to electricity, fuels, and thermal end uses.

2. Methodology

Bibliometrics takes the document system and bibliometric characteristics as the research object, adopts mathematical and statistical methods to research the distributed architecture, quantitative relation, varying pattern and quantitative management of the document information, and then investigates the structure, characteristics and patterns of the underlying science and technology.

2.1. The impact factor and h-index

The statistical analysis of documents is mainly targeted at published literature and authors. It is a necessary foundation and essential condition of document research. Publication statistics generally describe countries, publishing houses, subjects, languages, journals, research institutions and the number of published articles by different authors. Statistics on authors usually concentrate on the change of number of outstanding authors and ordinary authors over time.

Two measures of influence are used in our analysis: the impact factor (IF) and the h-index. The impact factor is one of the most influential tools in modern bibliometrics research. It is used in this paper to assess the solar energy-related journal's relative influence. The impact factor of a given journal was determined for each document as reported in the 2011 Journal Citation Reports. The h-index was first proposed by Hirsch to measure the productivity and impact of published works of not only scientists and scholars [12], but also research organizations, countries, and journals. It is a good indicator of the impact of a scientist or journal and has the advantage of being objective [13,14]. It is defined simply as: "A scientist has index H if H of his/her Np papers have at least H citations each, and the other (Np-H) papers have no more than H citations each," where Np is the number of papers published over *n* years [12]. Therefore, the h-index combines a measure of quantity (number of publications) and impact (number of citations) in a single indicator.

2.2. Content analysis

Word frequency analysis is a common form of content analysis. Investigators usually take core words and expressions which indicate the core content of literature as the research object. In this way, they can quantitatively analyze the development trends and changes in scientific research of a certain area. This study analyzes the keywords and headword field of publications and summarizes the hot research content in recent solar energy research.

2.3. The social network

Social network refers to the assemblage of social actors and the relationships between them. That is to say, a social network consists of multiple points (social actors) and the connections between them (the relationships between each social actor). Social network analysis involves quantitative research on the relationships between the social actors, which is presented as a useful extension of conventional forms of analysis. In this paper, this method is used to analyze the collaborative relationships among the 20 most productive countries and institutions.

3. Results

To conduct the pilot study, "solar energy" or "solar energies" is searched for titles, abstracts, and keywords in the database of the Science Citation Index (SCI) and the Social Science Citation Index (SSCI) on December 11, 2012. The documents were collected for the period during 1992–2011, and 7835 documents were obtained. The documents were analyzed according to their type, language(s), publication output, publication patterns, authorship, citation analysis of articles, impact factor (IF), country or countries of publication and keyword distribution, etc.

3.1. Characteristics of publications

These 7835 documents related to solar energy from the SCI and SSCI over the past two decades were categorized into 16 types. The most frequently used document type was "Article" with 86.4% (6770 records) of total publications, followed far behind by "Paper Proceedings" with a mere 11.6% (912 records), "Review" with 8.59%