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Past, current and future of biomass energy research: A bibliometric analysis

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ABSTRACT

This paper characterizes the body of knowledge on biomass energy from 1998 to 2013 by employing bibliometric techniques based on the Science Citation Index (SCI) databases of the Web of Science. Results showed that journal articles were the most frequently used document type representing 84.1% of the records. 33,072 articles were analyzed on various aspects of the publication characteristics such as authorship, countries, institutions, high-cited papers, and keywords. The pace of publishing in this field increased rapidly over last 16 years, with the US accounting for the highest *h*-index (137) and the most publications (8228), followed by China and India. The US also plays a central role in the collaboration network among the most productive countries. The Chinese Academy of Science was the organization with the most records (639). Similarly, the University of Illinois is central to the collaboration network. The hot spots of biomass energy related researches were transiting from physical conversion (6511 articles) to thermal chemical conversion (10,989) and biochemical (10,877).The bioenergy application (18,607) has become a main focus of current researches related to biomass energy. This topic mainly addresses biodiesel, biogas, biohydrogen, biofuel cell and so on. By identifying global hotspots in biomass energy research, this study is beneficial for researchers, e.g. the selection of future research topics. Similarly, policy makers will learn from the findings of this analysis with a good understanding of the status quo of biomass energy development.

Contents

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1. Introduction

The destabilization of the world's climate, arguably due to greenhouse gas emissions, 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 [1–4]. The sustainable development of alternative energy resources plays a vital role to mitigate issues associated with rapid urbanization and the continuous depletion of fossil fuels [5–8].

Biomass is the material derived from living or recently living organisms such as plants, animals and their byproducts [9–11]. Unlike conventional fossil fuels such as petroleum and coal, biomass is a source of renewable energy based on the carbon cycle [12–14].Thus, in virtue of its abundant resources, biomass is likely to be a prevalent option for generating electricity in the future [15]. As shown in Fig. 1, electricity net generation from biomass and waste of 5 major countries has achieved a continued growth [16].The US is far ahead of the other 4 countries. After 2009, the electricity net generation from biomass and waste surged in China. This shows that biomass energy have been receiving an increasingly level of attention over the world.

In view of this trend, the literature related to biomass energy has grown substantially. It calls for a timely study to implement bibliometric analytical techniques to evaluate the growing body of knowledge on biomass energy. According to Tsay, bibliometric technique provides a useful tool to quantitatively analyze the development of academic literatures of a particular subject [17]. Main advantages associated with bibliometric analysis are: (1) it allows the use of indicators and the calculation of certain classical laws to assess the research or scientific productivity in a specific area over a period of time [18,19,52,53];(2) it recognizes science as a knowledge-generating system [20,21].

This study aims to quantitatively and qualitatively evaluate the trends of the biomass energy related research literature from 1998 to 2013. Bibliometric methods are employed to examine various publication characteristics such as countries, research institutions, journals, research fields, and citation habits and content analysis. In addition, potential research directions are identified to promote the practical applications of biomass energy.

2. Methodology

Bibliometrics is a set of methods to take the bibliometric characteristics and document system as the research object [22,23]. It utilizes quantitative analysis and statistics to research the distributed architecture, quantitative relation, varying pattern as well as a quantitative analysis of the document information. Bibliometric methods can be used to investigate the structure, characteristics and patterns of the underlying science and technology.

2.1. The impact factor and h-index

As a vital foundation and essential condition of document research, the statistical analysis of documents mainly targeted at published authors and the literature. Publication statistics generally describe publisher, subjects, journal titles, academic institutions, countries and the number of articles published by different authors. Statistics on authors usually concentrate on the change of number of outstanding and ordinary authors over time.

In this study, two measures of influence are adopted, i.e. the impact factor (IF) and the *h*-index. Impact factor is a useful indicator for the quality of a journal. It is used in this paper to assess the relative influence of biomass energy-related journals. The impact factor of each individual journal was retrieved from the relative official website.

The *h*-index was first proposed by Hirsch to measure the productivity and impact of published works of scientists and scholars [24]. Such indicator could also be used to measure the productivity and impact of a group of scholars, such as university, country, or an academic journal. A simple definition of *h*-index is: “A scientist has index *H* if *H* of his/her Np papers have at least *H*

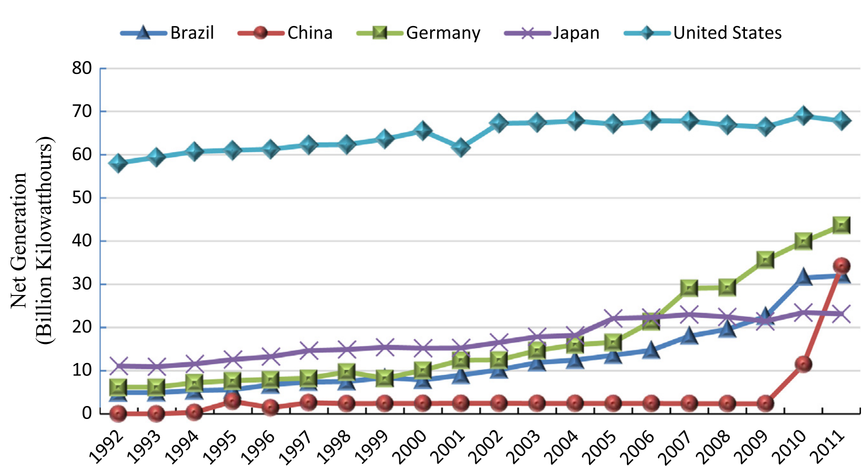

Fig. 1. Biomass and waste electricity net generation of 5 major countries during 1992–2011.

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 [24]. Therefore, the h-index covers both the impact (number of citations) and the quantity (number of publications) [25–27].

2.2. Content analysis

Word frequency analysis is a key way of content analysis. Researchers usually take keywords and expressions that indicate the core content of the literature as the research object [22]. In this way, the trends and changes in scientific research of a certain area can be analyzed quantitatively. This study analyzes the keywords and titles of publications in order to identify the hotspots of research in a specific field.

Table 1
Characteristics of publications from 1998 to 2013.

PY	TP	AUTP	No. AU	AU/TP	NR	NR/TP	PG	PG/TP
1998	374	374	1423	3.80	9987	26.70	3049	8.15
1999	407	407	1536	3.77	10,146	24.93	3227	7.93
2000	483	482	918	1.90	12,018	24.88	3946	8.17
2001	429	429	429	1.00	11,739	27.36	3678	8.57
2002	474	472	472	1.00	12,523	26.42	3911	8.25
2003	620	617	617	1.00	16,708	26.95	5464	8.81
2004	640	640	640	1.00	18,305	28.60	5857	9.15
2005	790	788	788	1.00	22,789	28.85	7073	8.95
2006	981	975	975	0.99	26,645	27.16	8142	8.30
2007	1501	1493	1493	0.99	42,816	28.52	12,845	8.56
2008	2223	2218	2218	1.00	65,473	29.45	18,212	8.19
2009	3046	3046	3046	1.00	97,868	32.13	25,600	8.40
2010	3985	3984	3984	1.00	135,847	34.09	34,283	8.60
2011	5036	5028	5028	1.00	181,811	36.10	44,282	8.79
2012	5836	5835	5835	1.00	219,110	37.54	52,791	9.05
2013	6247	6245	6245	1.00	237,805	38.07	56,937	9.11

PY: year; TP: the number of total publications; AUTP: the number of publications including authors' names; AU: the number of authors; NR: the number of cited reference; PG: the number of pages; AU/TP, PG/TP, and NR/TP: the average of authors, pages, and references in a paper.

2.3. The social network

The social network has been a common tool in the social sciences to explore relationships between social actors [28,29]. In other words, a social network consists of multiple points (social actors) and the connections between them (the relationships between each social actor) [30]. In this paper, social network method is employed to investigate the collaborative relationships among the 20 most productive countries and institutions.

3. Results

The following phrases were used to search titles, abstracts, and keywords in the database of the Science Citation Index (SCI):"biomass energy" or "biomass energies" or "bio-mass energy" or "bio-mass energies" or "biofuel*" or "bio-fuel*" or "bioenergy" or "bio-energy" or "bioenergies" or "bio-energies" or "biogas" or "bio-gas" or "bioelectric*" or "bio-electric*" or "bioethanol" or "bio-ethanol" or "biodiesel" or "bio-diesel".

The search was conducted on 17 January 2014 to collect documents published between 1998 and 2013 in English. The documents were analyzed according to characteristics of publications such as patterns, authorship, citations, and impact factor (IF).

3.1. Characteristics of publications

A total of 40,802 documents related to biomass energy were retrieved from the SCI database over the past 16 years. These documents were categorized into 14 types. The most frequently used document type was "Article" which accounted for 80.1% (33,072 records) of total publications. It is followed far behind by "Review" with a mere 7.2% (2938 records), "Proceedings paper" with 5.04% (2060 records), "Meeting Abstract" with 3.45% (1411records) and "News Item" with 2.74% (1119 records). The records of other types accounted for less than 2%, such as Editorial Material, Letter, Book Chapter, Correction, Reprint, Book Review, Biographical Item, Bibliography and Software Review.

In this paper, only the type of "Article" is considered. The articles pertaining to biomass energy in the SCI are available in 28 languages. English is the dominant language with 31,835 records.

Table 2
The top 20 productive countries/territories during 1998–2013.

Country	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	RP R (%)	h-index
USA	8228	1(25.02)	1(22.49)	1(36.05)	1(21.46)	1(21.58)	137
China	3513	2(10.68)	2(9.35)	2(16.47)	2(9.23)	2(9.16)	77
India	1841	3(5.6)	3(5.68)	14(5.26)	3(5.07)	3(5.01)	62
Brazil	1783	4(5.42)	4(5.33)	12(5.81)	4(4.91)	4(4.87)	49
Germany	1725	5(5.25)	6(3.66)	3(12.14)	5(3.93)	5(3.93)	69
UK	1644	6(5)	9(3.43)	4(11.83)	7(3.72)	7(3.72)	75
Japan	1512	7(4.6)	5(3.97)	9(7.32)	6(3.83)	6(3.83)	64
Spain	1435	8(4.36)	8(3.49)	6(8.15)	8(3.64)	8(3.66)	61
Italy	1372	9(4.17)	7(3.64)	10(6.48)	9(3.53)	9(3.5)	55
Canada	1264	10(3.84)	11(2.98)	8(7.58)	10(3)	10(3.03)	60
Sweden	1181	11(3.59)	13(2.65)	7(7.7)	11(2.8)	11(2.83)	59
France	1099	12(3.34)	14(2.23)	5(8.19)	14(2.35)	14(2.4)	59
South Korea	1041	13(3.17)	12(2.78)	15(4.83)	12(2.74)	12(2.78)	42
Turkey	931	14(2.83)	10(3.15)	36(1.43)	13(2.72)	13(2.73)	58
Netherlands	838	15(2.55)	16(1.67)	11(6.38)	15(1.87)	15(1.84)	67
Australia	757	16(2.3)	17(1.6)	13(5.34)	17(1.68)	16(1.72)	50
Taiwan	624	17(1.9)	15(1.75)	23(2.54)	16(1.71)	17(1.72)	37
Denmark	606	18(1.84)	19(1.19)	16(4.7)	19(1.37)	19(1.38)	48
Malaysia	553	19(1.68)	18(1.35)	20(3.14)	18(1.43)	18(1.4)	37
Finland	537	20(1.63)	20(1.16)	19(3.71)	20(1.27)	20(1.27)	39

TP: the number of total publications; SP: the number of single country publications; CP: the number of internationally collaborative publications; FP: the number of publications as first author's country; RP: the number of publications as corresponding author's country; R (%): the rank and the ratio of the number of one country's publications to the total number of publications during 1998–2013.

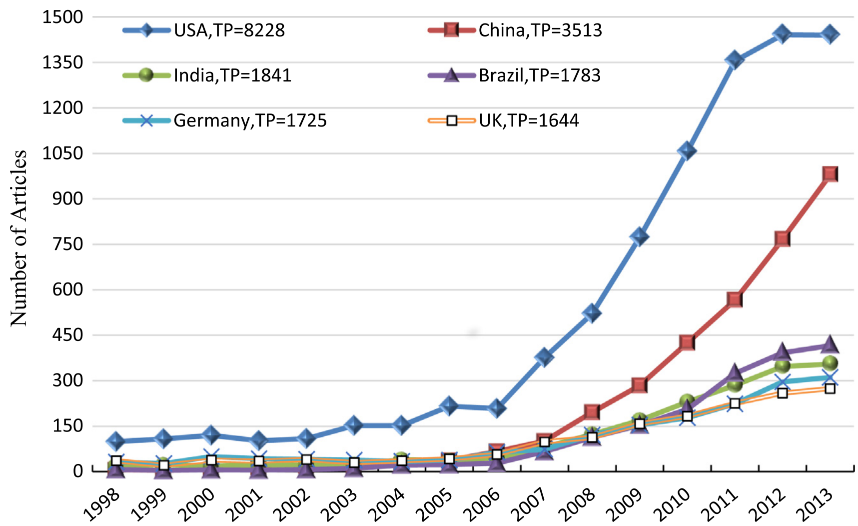

Fig. 2. The annual number of each top 6 productive country during 1998–2013.

There were other languages used more than 100 times in articles such as Portugue (263), German (224), Spanish (150) and Polish (136). English was the dominant language in biomass energy research, even in many non-English speaking countries including China, Germany and Japan. This suggests that the English language is a common medium of communication in these research activities.

Table 1 presents key characteristics of the biomass energy related publications between 1998 and 2013. As shown in Table 1, the number of articles and the number of cited references increased significantly every year, so as to the average number of authors. Between 1998 and 2000, the rate of publication on biomass energy grows by about 29%. It then experiences a slight decrease in 2001, followed by a steady growth every year through to 2013. From 2005 to 2011, the pace of publication increases substantially, with an average annual growth rate greater than 20%. After 2011, the growth begins to slow down. There was an average of 3.8 authors per biomass energy related article in 1998, whereas this number steadily decreased to 1.0 in 2001. The number of references rose from 26.70 in 1998 to 38.07 in 2013. The progressive growth of publications and associated references indicate the stable development and communication in the field of biomass energy research during the past 16 years.

3.2. *Publication distribution of countries/territories and institutes*

The contribution of different countries/territories and institutes can be evaluated by means of the address and affiliations of at least one author of journal articles. Only 32,883 articles could be used to analyze the distribution of countries/territories and institutes because 189 articles do not include author addresses in the SCI database. Of these 32,883 articles, only 6144 (18.7%) articles involve international collaborations. The international collaborative publication was assigned if authors resided in different countries otherwise the single-country publication was assigned [31].

From 1998 to 2013, 144 countries have contributed to biomass energy research by means of publishing academic articles in the SCI database. Three quarters of the world's countries have scientists who publish in the field of biomass energy. While this shows a great geographic breadth, the top 20 countries are responsible for 98.8% of the total amount of publications.

The 20 most productive countries/territories are ranked using the following indicators: the number of total journal articles, the number and the percentage of single country articles and internationally collaborated articles, the first author and corresponding author articles, and so on (see Table 2). In the top 20 countries, there are two countries from North America, seven countries/territories from Asia, nine countries from Europe, one country (Australia) from Oceania, one country (Brazil) from South America. The US is the most productive country with the largest number in all aspects, followed by China. It is worth noting that China ranks second in the top 20 productive countries/territories, but has a large gap compared to US in every single aspect. India and Brazil rank third and fourth respectively in terms of the number of total publications, single country publications and publications with first author. However, for the number of internationally collaborative publications, India is in the 14th place and Brazil is in 12th. Thus it can be observed that international cooperation in biomass energy depends in part on geographic region and economic development. By contrast, Germany and the U.K. have less number of total publications, but 11–13% of them involve international collaboration.

Fig. 2 displays the time-trend analysis of the 6 most productive countries. Obviously the US took a leading position during the whole period, with its published articles growing rapidly after 2006. This is arguably due to the Energy Policy Act enacted by the government in 2005. Similar to the US, the growth rate of publications in China is much higher than the other 5 dominant countries since 2007. The Renewable Energy Sources Act was introduced to China in 2006. Thus, the research on biomass energy has achieved significant development under the promotion and guidance of regulations, laws such as the 2010–2020 Renewable Energy Medium and Long-term Development Plan. In contrary, the number of articles on biomass energy by Brazil, India, Germany and UK increased slowly. It can be observed from Fig. 2 that the rapid development of biomass energy research was substantially driven by these highly productive countries.

The cooperative relationships among the top 30 productive countries and regions in the field of biomass energy research from 1998 to 2013 are obtained, as defined by the cooperation network diagram shown in Fig. 3. As shown in Fig. 3, the US has played a key role in the collaboration network of the 30 productive countries and regions with existing collaboration with every single member of the network. Among them, the cooperation between the US and China is particularly notable, rising to the first place in terms of intensity. Similarly, the number of cooperation between the US and Canada, the UK, South Korea, Germany and Brazil are also substantial. This is probably why the US is the most productive country with the largest annual number of publications. China had partnerships with several other countries, mainly centered on the Japan, Canada and Germany. Therefore, effective international cooperation plays a

Fig. 3. The cooperation network of the top 30 productive countries/territories.

Table 3
The performance of the top 10 most productive institutions.

Institution name	TP	TP *R* (%)	SP *R* (%)	CP *R* (%)	FP *R* (%)	RP *R* (%)	*h*-index
Chinese Academic of Science, China	639	1(1.94)	1(1.23)	1(2.59)	1(1.36)	1(1.35)	41
USDA ARS, USA	317	2(0.96)	5(0.67)	3(1.23)	3(0.65)	3(0.64)	44
University of Illinois, USA	315	3(0.96)	11(0.59)	2(1.29)	5(0.63)	5(0.59)	34
Agricultural Research Service, USA	313	4(0.95)	5(0.67)	5(1.21)	4(0.63)	4(0.63)	52
University of Sao Paulo, Brazil	291	5(0.88)	13(0.51)	4(1.22)	9(0.54)	10(0.49)	22
Indian Institute of Technology, India	265	6(0.81)	2(1.15)	47(0.49)	2(0.67)	2(0.67)	38
Iowa State University, USA	263	7(0.8)	3(0.75)	11(0.85)	6(0.57)	7(0.56)	32
Technical University of Denmark, Denmark	262	8(0.8)	8(0.65)	10(0.93)	7(0.56)	6(0.56)	43
Lund University, Sweden	258	9(0.78)	9(0.6)	9(0.95)	8(0.55)	8(0.54)	44
University of California Berkeley, USA	247	10(0.75)	35(0.31)	6(1.15)	18(0.35)	17(0.36)	37
Swedish University of Agricultural Sciences, Sweden	231	11(0.7)	4(0.73)	21(0.68)	10(0.52)	9(0.52)	29
University of Wisconsin, USA	231	11(0.7)	17(0.42)	8(0.96)	14(0.42)	14(0.4)	31
University of Minnesota, USA	227	13(0.69)	9(0.6)	17(0.77)	12(0.46)	12(0.45)	31
Tsinghua University, China	223	14(0.68)	12(0.52)	12(0.82)	11(0.49)	11(0.49)	30
Oak Ridge National Laboratory, USA	217	15(0.66)	63(0.22)	7(1.06)	26(0.3)	26(0.29)	33
Michigan State University, USA	216	16(0.66)	14(0.5)	15(0.8)	13(0.45)	13(0.44)	31
University of California Davis, USA	194	17(0.59)	20(0.4)	18(0.77)	16(0.37)	16(0.38)	27
Texas A&M University, USA	192	18(0.58)	30(0.33)	12(0.82)	20(0.32)	20(0.32)	26
University of Estadual Campinas, Brazil	187	19(0.57)	23(0.38)	19(0.74)	19(0.35)	19(0.33)	24
University of Georgia, USA	181	20(0.55)	43(0.27)	14(0.81)	23(0.31)	21(0.31)	28

TP: the number of total publications; SP: the number of single institute publications; CP: the number of inter-institutionally collaborative publications; FP: the number of publications of as the first author's institute; RP: the number of publications as corresponding author's institute; *R* (%): the rank and the ratio of the number of one institute's publications to the total number of publications during 1998–2013.

critical role to promote the researches on biomass energy. Indeed, the US has been ahead of other countries in terms of biomass energy researches because of the infrastructure for international cooperation. Similarly, the biomass energy industry in China has experienced a rapid growth as a result of regional and national cooperation.

A total of 14,345 institutions contributed to the subject of biomass energy according to the 32,883 articles with author addresses information. More than half of these articles (52.4%) involve multi-institutional collaborations. The contribution of the 20 most productive institutes in biomass energy research from 1998 to 2013 is shown in Table 3. Among the top 20 institutes, 12 institutes are from the US; two from China, Sweden and Brazil; one from India and Denmark respectively. Germany, UK, Japan, Spain, Italy, France, South Korea, Turkey, Netherlands, Australia, Taiwan region and Finland belonged to the 20 most productive countries/regions. However, no institutes from these countries appear in the list of the 20 most productive institutes. The Chinese Academy of Science had the maximum contribution in terms of the total volume of publications with 639 articles, followed by the United States Department of Agriculture-Agricultural Research Service in the US (317 articles) and the University of Illinois (315 articles). It is worth noting that the *h*-index of the Chinese Academy of Sciences is not the highest despite its top ranking.

The growth of the 6 most productive institutes over 16 years is revealed in Fig. 4. Before 2007, research on biomass energy was developed steadily in all 6 institutes, while biomass energy research by the Chinese Academy of Sciences surged after 2007 especially after 2009.Since 2010, it can be observed that the number of publications from the Chinese Academy of Science's is much more than that of the other 5 institutes. These publications provide useful inputs for policy making process in terms of biomass energy development.

The cooperative relationship among the most productive institutions in the field of biomass energy research from 1998 to 2013 is also analyzed. The corresponding cooperation network diagram is shown in Fig. 5.

As shown in Fig. 5, University of Tennessee and Oak Ridge National Laboratory, both from the US, have a strong cooperation relationship. They have produced 60 co-authored publications. It is worth noting

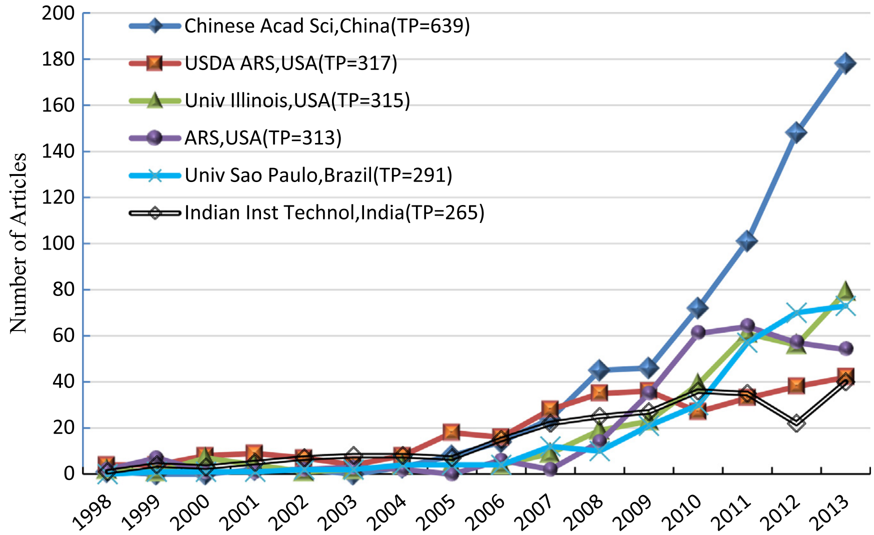

Fig. 4. The growth trend of the top 6 productive institutes during 1998–2013.

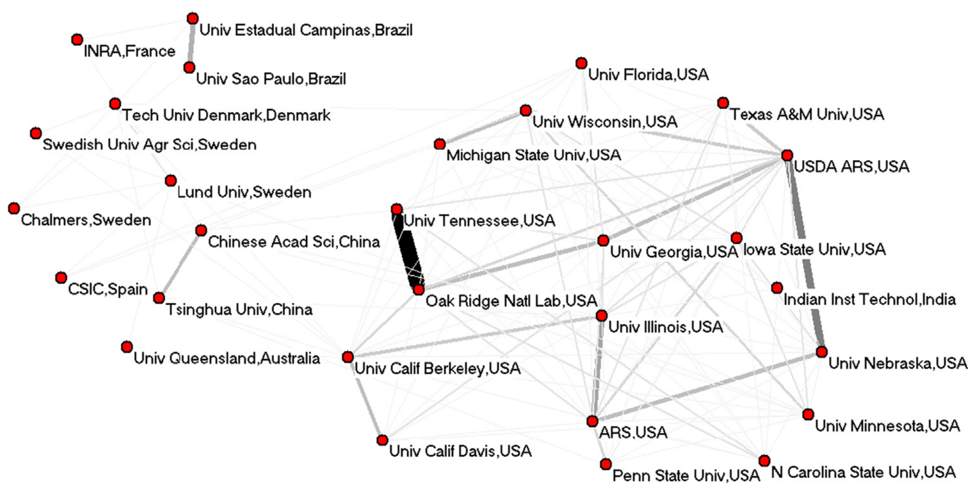

Fig. 5. The cooperation network of the top 30 productive institutions.

Table 4
The top subordinates of the top 3 institutions.

Institution	Subordinate	TP
Chinese Academic of Science, China	Graduate University/Graduated School	171
	Qingdao Institute of Bioenergy and Bioprocess Technology	67
	Dalian Institute of Chemical Physical	58
	Guangzhou Institute of Energy Conversion	46
	Changchun Institute of Applied Chemistry	35
The United States Department of Agriculture-Agricultural Research Service, USA	National Center for Agricultural Utilization Research	65
	U.S. Dairy Forage Research Center	28
	Eastern Regional Research Center	19
	Southern Regional Research Center	11
	Western Regional Research Center	11
University of Illinois, USA	Institute for Integrative Genome Biology	67
	Energy Biosciences Institute	66
	The Department of Crop Science	60
	The Department of Plant Biology	33
	Department of Agricultural & Biological Engineering	30

that most of cooperation relationships are among the American institutions. University of Illinois in the US is in the center of the collaboration network, having cooperation relationship with other19 institutes, especially with the Agricultural Research Service, USA. These two US institutes have produced 23 co-authored publications. Chinese Academy of Sciences also has good cooperative relationships with other 14 institutes, especially with Tsinghua University, China. In contrast, the two Brazil institutes, University of Sao Paulo and University of Estadual Campinas, have a strong cooperation relationship, but have limited cooperation with overseas institutes. The institutes in Sweden, Demark and India also appear to have minimal international collaboration. Other institutes' linkages to the rest of the research network shown in Fig. 5 are enabled by their ties. It can be concluded that the US plays a significant role in the cooperation network of countries and institutions. The US has a very active academic atmosphere to make it the most productive country with the largest number in every aspect. In addition, all the research institutions are inclined to cooperate with other domestic institutions. Therefore, more efforts are required to promote the cooperation with overseas institutions for the research and development of biomass energy.

Based on the institution level analysis, the top 3 institutes are analyzed thoroughly for their departments (Table 4). Graduate University of Chinese Academy of Sciences (171) and Natural Center for Agricultural Utilization Research (65) occupy the first place in the rankings of departments of Chinese Academy of Science and USDA ARS respectively. These two departments have much more biomass energy related publications than other departments of each individual institute. In University of Illinois, the top 3 departments are Institute for Integrative Genomic Biology (67), Energy Biosciences Institute (66) and the Department of Crop Sciences (60).

Table 5
The 20 most productive subjects during 1998–2013.

Subject	TP	%
Energy & Fuels	10,268	31.06
Engineering	8963	27.12
Biotechnology & Applied Microbiology	7513	22.73
Agriculture	5852	17.70
Chemistry	5473	16.56
Environmental Sciences & Ecology	4777	14.45
Biochemistry & Molecular Biology	1412	4.27
Electrochemistry	1217	3.68
Nutrition & Dietetics	1060	3.21
Thermodynamics	1058	3.20
Food Science & Technology	1057	3.20
Materials Science	933	2.82
Science & Technology – Other Topics	926	2.80
Water Resources	781	2.36
Physics	779	2.36
Plant Sciences	662	2.00
Endocrinology & Metabolism	602	1.82
Microbiology	577	1.75
Meteorology & Atmospheric Sciences	476	1.44
Forestry	445	1.35

TP: the number of total publications.

3.3. Subjects covered by biomass energy publications

The 33,072 articles for biomass energy analysis are divided into 129 subject categories in the SCI database. The contribution of the top 20 subjects in biomass energy research from 1998 to 2013 is shown in Table 5. Energy & Fuels is the most popular topic, with 10,268 records, followed by Engineering with 8963 records and Biotechnology & Applied Microbiology with 831records. The contribution of the top 6 subjects to the total number of publications is over 10%.

Fig. 6 illustrates the five most frequent subject categories in terms of the number of annual publications for the set of 33,072 articles. The numbers of articles in these five subject categories soared during the period from 2009 to 2013. Energy & Fuels had been in a leading position during 2009–2013. The other four subjects grow more rapidly since 2007. In sum, the main research area of biomass energy is Energy & Fuels and Engineering from 1998 to 2013.

A total of 2975 journals published papers on biomass energy research all over the world during 1998–2013. More than 30% of the biomass energy related articles are published in the top 20 journals listed in Table 6. *Bioresource Technology* is the most productive journal with 2271 articles, followed by *Biomass &Bioenergy* (1332) and *Fuel* (857). It is worth mentioning that the *Biotechnology for Biofuels* ranks 15th in the number of articles, but with the highest IF value (5.55) among these 20 journals. Fig. 7 shows the publication pattern of the top 5 journals. It is notable that *Bioresource Technology* soars rapidly after 2009, while the other four journals fluctuate during the last 16 years.

3.4. Main research hotspots for biomass energy

Numerous key points have been investigated in biomass energy research field. It is crucial to identify the development trend of these key points. Yaoyang and Boeing demonstrate hotspots of biomass energy that relies on intellectual connection of keywords [32]. They are product, biomass, conversion route, conversion process, fuel cells and life cycle assessment. In this study, the review and analysis of keywords from retrieved articles can be organized around hot topics that are related to biomass energy. These include basic conversion process and application, such as physical conversion, chemical/thermal chemical conversion, biochemical conversion and bioenergy application. The ranking of keywords and hotspot analysis of publications on biomass energy

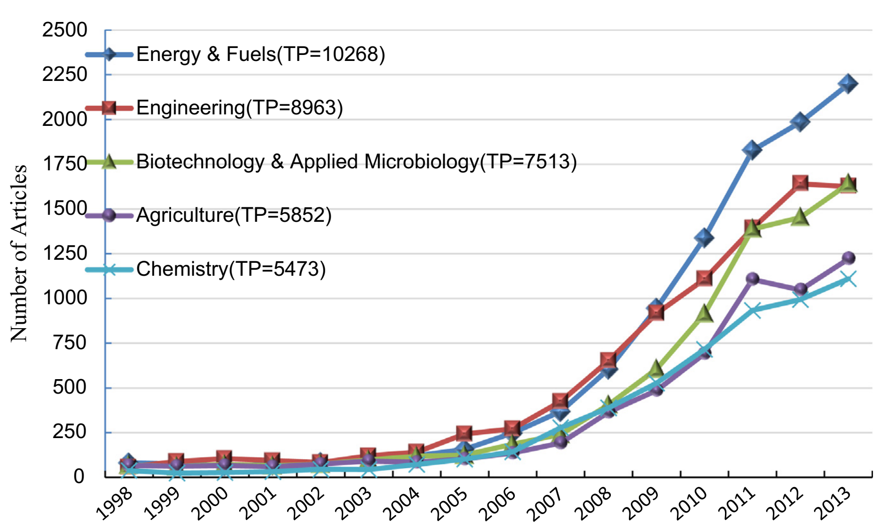

Fig. 6. The number of articles of the top 5 productive subject categories.

Table 6
The 20 most productive journals during 1998–2013.

Journal name	*R*	TP (%)	IF 2012
Bioresource Technology	1	2271(6.87)	4.75
Biomass & Bioenergy	2	1332(4.03)	2.975
Fuel	3	857(2.59)	3.357
Energy & Fuels	4	717(2.17)	2.853
Applied Energy	5	474(1.43)	4.781
Energy Policy	6	470(1.42)	2.743
International Journal of Hydrogen Energy	7	457(1.38)	3.548
Water Science and Technology	8	380(1.15)	1.102
Energy	9	371(1.12)	4.107
Renewable Energy	10	369(1.12)	2.989
Industrial & Engineering Chemistry Research	11	356(1.08)	2.206
Fuel Processing Technology	12	318(0.96)	2.816
Applied Biochemistry and Biotechnology	13	318(0.96)	1.893
Environmental Science & Technology	14	272(0.82)	5.257
Biotechnology for Biofuels	15	249(0.75)	5.55
Journal of the American Oil Chemists Society	16	243(0.73)	1.592
Energy Sources Part A – Recovery Utilization and Environmental Effects	17	243(0.73)	0.516
Bioenergy Research	18	236(0.71)	4.25
Industrial Crops and Products	19	226(0.68)	2.468
Applied Microbiology and Biotechnology	20	224(0.68)	3.689

TP: the number of total publications; *R*: the rank; (%): the ratio of the number one journal's publications to the total number of publications during 1998–2013; IF: impact factor.

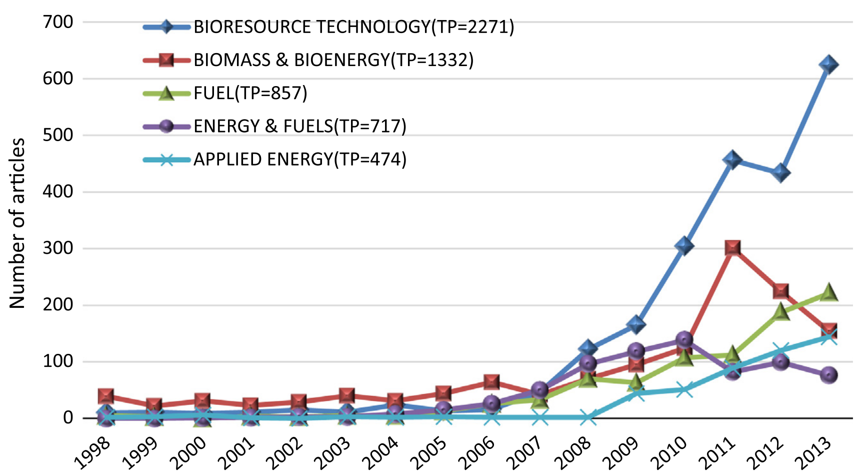

Fig. 7. The number of articles of the top 5 productive journals during 1998–2013.

are shown in Table 7.As shown in Table 7, the largest number of retrieved journal articles is in the area of bioenergy application (18,607), followed by biochemical conversion (10,877 articles) and chemical/thermal chemical conversion (10,989). Less research attention is paid to topics such as physical conversion (6511).

3.4.1. *Physical processing or conversion*

Some agricultural products are specifically grown for biofuel production, such as switchgrass, corn stover, miscanthus and rice straw. These materials can be prepared into pellets or compression molding. They are now considered for use in direct combustion for thermal energy applications. Under this topic, 6511 publications were retrieved in the SCI database. This type of agricultural waste or plants grown specifically for energy production becomes cost competitive compared to fossil fuels. Switchgrass related research has reached the pre-commercial level, particularly in the United States. Similarly, corn stover, wheat straw and rice straw can be used as biofuel after compression and pelletization [33,34]. These related technologies have become mature. It can be observed that the topic of combustion (2754) is the top subject, followed by straw (1339) and switchgrass (823).

3.4.2. *Chemical or thermal chemical conversion*

Chemical or thermal chemical conversion processes is the most common mechanism to convert biomass into another chemical form. The basic methods include esterification/transesterification (3849) and pyrolysis (1051). Under this topic, 10,989 publications were retrieved in the SCI database. In 2007, biodiesel production capacity grew rapidly, and its benefits receive an increasingly level of attention from many countries. The main production reaction, esterification/transesterification, is the area with greatest potential of research. The base-catalyzed fast transesterification of characterization are already characterized, but there is a lot of room for future research. Similarly, the raw material of biodiesel, such as microalgae, has become a key point of biomass energy related studies. From 2010 to 2013, the number of researches on microalgae surged. This is probably due to a high heating value of biomass fuel prepared by microalgae pyrolysis, which is 1.4–2.0 times higher than that of wood and straw. In the future, microalgae could be considered as one of the best choices of biodiesel raw materials.

Cellulose (2602) and lignin (1372) are the major component of non-food energy crops. Their converted products, liquid fuel, are known as second-generation liquid biofuels and will be the alternatives of traditional fossil fuel [35]. Despite significant progress to overcome the economic and technical challenges, high cost remains

Table 7
The number of publications by main topic and subtopic.

Main topics and subtopics	Number of publications (1998–2013)	Number of publications (1998–2001)	Number of publications (2002–2005)	Number of publications (2006–2009)	Number of publications (2010–2013)
Physical processing or conversion	6511	130	355	1389	4637
Combustion (Biomass combustion; combustion process)	2754	101	183	675	1795
straw	1339	33	49	232	1025
Wheat straw	316	1	16	55	244
Rice straw	302	6	4	33	259
Switchgrass	823	22	33	137	631
Corn stover	795	1	23	145	626
Miscanthus	416	6	10	66	334
Pellet (pellets; pelleting; pelletization)	302	6	20	74	202
Chemical or thermal chemical conversion	10,989	190	421	2348	8030
Esterification/transesterification (trans-esterification)	3849	51	144	1046	2607
Pretreatment (pre-treatment)	2647	43	82	439	2083
Cellulose (hemicellulose; hemicelluloses)	2602	28	74	422	2078
Lignin (lignocellulose; lignocellulose)	1372	10	28	230	1104
Microalgae	1358	4	5	79	1270
Pyrolysis	1051	18	38	244	751
Biochemical or biological conversion	10,877	299	560	2447	7571
Fermentation	3737	70	140	732	2795
Bioethanol (bio-ethanol; bio ethanol)	3699	39	115	801	2744
Ethanol (ethanol fuel; fuel ethanol)	2940	32	87	663	2158
Methane (biomethane)	2934	167	255	729	1783
Anaerobic digestion (anaerobic digestion process)	1938	109	177	484	1168
Saccharomyces cerevisiae	742	4	25	140	573
Bioenergy application	18,607	608	1121	4584	12,294
Biodiesel (biodiesels; biodiesel fuel; biodiesel fuels)	10,062	148	343	2380	7191
Biogas (biogas energy)	4858	358	527	1237	2736
Hydrogen (biohydrogen)	3003	61	158	740	2044
Biofuel cell(biofuel cells; Fuel cell; fuel cells)	2262	29	176	658	1399
Heating (district heating)	1237	68	92	310	767
Generation	1205	39	98	273	795
Electricity generation(power generation; energy generation; bioelectricity generation)	887	31	71	190	595
Cogeneration (co-generation; polygeneration; combined heat and power; trigeneration; tri-generation)	384	10	33	98	243

the most significant challenge to the second-generation biofuels production. Therefore, it is necessary to improve the performance of the conversion process in order to reduce costs [36–38].

During the past few years various pretreatment techniques have been developed. The purpose of pretreatment is to make the cellulose and lignin accessible to hydrolysis for conversion to fuels [39,40].The analysis shows that pretreatment, as a keyword of publications is in the second place of the field of research on biomass energy. By 2013, the number of publications related to pretreatment has soared to 2083.

3.4.3. Biochemical or biological conversion

Biochemical or biological conversion breaks down biomass by means of the enzymes of bacteria and other microorganisms. The conversion processes include fermentation (3737), and anaerobic digestion (1938). Under this topic, 10,877 publications were retrieved from the SCI database. In this field, the main topics include three kinds of reaction and product, and a species of yeast. In recent years, the conversion of biomass into fuel ethanol (2940) or bioethanol (3699) attracted a lot of attention. These products are considered as the cleanest liquid fuel alternative to fossil fuels therefore significant efforts have been made on fermentation technologies [41–43]. As a result, it is worth of investigation of fermentations employed in commercial fuel ethanol and bioethanol production.

The other important biochemical conversion is anaerobic digestion. It is a biological process in environments with little or no oxygen. Anaerobic digestion produces biogas which is comprised of about 60% methane (CH_4) and 40% carbon dioxide (CO_2) [44]. Thus, several research groups have been engaged in research of upgrading the biogas for biomethane production. By biogas upgrader, methane in biogas can be concentrate to natural gas standards. Then it goes through a cleaning process and becomes biomethane (2934). This biomethane may be considered as a substitute to natural gas and 33% of natural gas may be substituted by 2020 [45].

3.4.4. Bioenergy application

Biomass can be converted to some usable forms of energy including transportation fuels, such as biodiesel and bioethanol; or biogas, such as biomethane. As a result, the technologies of district heating (1237), biomass power generation and combined heat and power (1205) have become the research priorities of many countries and regions. Household biogas systems are introduced in rural areas in China as a national initiative to improve energy efficiency [46]. In the United States, the Energy Independence and Security Act was enforced to facilitate the biofuel production. It has been estimated that bioenergy will contributed 60% of the total renewable energy in 2020 [47]. Policies have been enforced in the European Union to support bioenergy production and trade. The annual demand for biomass for energy will double by 2020 [48].Indeed, biomass energy plays a vital role in renewable energy development.

Under this topic, 18,607 publications were retrieved from the SCI database. It accounts for one-third of total amount of documents. Biodiesel (10,062) and biogas (4858) are the two most important applications of biomass energy. In virtue of environmental benefits, biodiesel seems to be an environmentally friendly fuel that can replace diesel fuel in vehicle engines. Biogas can be used for

Table 8
Most frequently cited articles during 1998–2013.

Year	TC-2013	TC/Y	Article	Journal	Country
1998	309	19	A comparison of chemisorption kinetic models applied to pollutant removal on various sorbents	Process Safety and Environmental Protection	China
1999	2652	177	Pseudo-second order model for sorption processes	Process Biochemistry	China
2000	348	25	Affective picture processing: the late positive potential is modulated by motivational relevance	Psychophysiology	USA
2001	394	30	Biodiesel fuel from rapeseed oil as prepared in supercritical methanol	Fuel	Japan
2002	404	34	Effect of pH on hydrogen production from glucose by a mixed culture	Bioresource Technology	China
2003	560	51	An inventory of gaseous and primary aerosol emissions in Asia in the year 2000	Journal of Geophysical Research-Atmospheres	USA, China, Austria
2004	450	45	Global potential bioethanol production from wasted crops and crop residues	Biomass & Bioenergy	USA
2005	536	60	Synthesis of biodiesel via acid catalysis	Industrial & Engineering Chemistry Research	USA
2006	1028	129	Ethanol can contribute to energy and environmental goals	Science	USA
2007	394	56	Metagenomic and functional analysis of hindgut microbiota of a wood-feeding higher termite	Nature	USA, Costa Rica
2008	1199	200	Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change	Science	USA
2009	420	84	Microalgae for oil: strain selection, induction of lipid synthesis and outdoor mass cultivation in a low-cost photobioreactor	Biotechnology and Bioengineering	Italy
2010	356	89	Sarcopenia: European consensus on definition and diagnosis	Age and Ageing	Spain, Belgium, Germany, France, Sweden, Italy, UK, Switzerland, Czech Republic
2011	175	58	Metagenomic Discovery of Biomass-Degrading Genes and Genomes from Cow Rumen	Science	USA
2012	65	33	The Genome Portal of the Department of Energy Joint Genome Institute	Nucleic Acids Research	USA
2013	49	49	Porous materials with optimal adsorption thermodynamics and kinetics for CO_2 separation	Nature	USA, Saudi Arabia

TC: total citations; TC/Y: average annual citations since publication.

electricity production and heating. If concentrated and compressed, it also can be used in vehicle transportation. In the future, biodiesel and biogas will remain the key applications of biomass energy.

Biohydrogen (3003) is a new type of biofuel which is defined as hydrogen produced by algae, bacteria and other biomass materials. Currently, it is considered as a vital key to a sustainable power supply and potentially the ideal way of renewable H_2 production technology [49,50]. However, the future research and development will place focus on developing biohydrogen production methods for commercialization.

Another bioenergy application is biofuel cell (2262). Biofuel cell is a specific type of fuel cell that uses enzymes bacteria and other micro-organisms as catalyst to oxidize the fuel. Although biofuel cells are only used in laboratories, they are still perceived as next-generation energy device with high energy density and safety [51]. In this field, analysis showed that “biofuel cell” is ranked fourth in terms of the total frequency of keywords and has achieved rapid development since 2010.

3.5. The most highly cited articles

The most highly cited articles are analyzed with parameters such as the total citations, average annual citations, and the country of origin, for 1998–2013 (see Table 8).Yearly variations in the number of citations can be used to trace the impact of publications. It can be observed that the most highly cited article is entitled “Pseudo-second order model for sorption processes” authored by Ho YS and McKay G, which was published in Process Biochemistry in 1999, with 2652 citations. The second most highly cited paper is entitled “Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change” published in Science in 2008, with 1199 citations and the most annual citations at 200. Significant progress has been made in the fields of biodiesel, bioethanol and biofuel. A large number of articles have been published on these subjects with high number of citations, which reflects their significant impacts on biomass energy research [54].

4. Conclusions

Based on the SCI database, the characteristics of the biomass energy related literature from 1998 to 2013 are examined by means of bibliometric methods. This paper reveals that the literature on biomass energy has become more extensive and global over the past 16 years. In language analysis, 96.4% were published in English. The US is one of most important contributors to the biomass energy literature with the highest *h*-index (137) and the most number of publications (8228), followed by China and India. Similarly, the US has played a vital role in the collaboration network of the 20 productive countries and regions. The Chinese Academy of Science is the institution making most significant contribution towards biomass energy research (publishing 639 papers).The University of Illinois in the US is in the center of the collaboration network among the 20 most productive institutions, having strong cooperation relationships with other 15 institutes, especially with the Agricultural Research Service, USA.

The study also revealed that five core journals, namely *Bioresource Technology*, *Biomass & Bioenergy*, *Fuel*, *Energy & Fuels and Applied Energy*, contribute about 17% to the total number of journal publications on biomass energy. “Energy & Fuels” is the hottest subject with the highest number of biomass energy publications. The analysis showed that the most highly cited article is “Pseudo-second order model for sorption processes”, authored by Ho YS and McKay G, and published in Process Biochemistry in 1999, with 2652 citations. The main topic and subtopic analysis indicated that biodiesel and biogas are the most popular applications of bioenergy. Similarly, bioethanol, as another alternative biofuel, has also attracted wide attention. The rapid growing biotech researches of transesterfication, fermentation and pretreatment have been carried out. These researches will lay a solid foundation for future technology breakthroughs in biomass energy conversion.

These results illustrate the value of bibliometric techniques to reveal global research trends of biomass energy. Thus, this research provides a useful reference for biomass fuel manufacturers, academics, biomass energy researchers, and policy decision makers.

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References

[1] Knox-Hayes J, Brown MA, Sovacool BK, Wang Y. Understanding attitudes toward energy security: results of a cross-national survey. Glob Environ Chang 2013;23:609–22.
[2] Kaygusuz K. Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey. Renew Sustain Energy Rev 2009;13:253–70.
[3] Khan MA, Khan MZ, Zaman K, Khan MM, Zahoor H. Causal links between greenhouse gas emissions, economic growth and energy consumption in Pakistan: a fatal disorder of society. Renew Sustain Energy Rev 2013;25:166–76.
[4] Khan MA, Khan MZ, Zaman K, Naz L. Global estimates of energy consumption and greenhouse gas emissions. Renew Sustain Energy Rev 2014;29:336–44.
[5] Sajjad H, Masjuki HH, Varman M, Kalam MA, Arbab MI, Imtenan S, et al. Engine combustion, performance and emission characteristics of gas to liquid (GTL) fuels and its blends with diesel and bio-diesel. Renew Sustain Energy Rev 2014;30:961–86.
[6] Shi Q, Zuo J, Huang R, Huang J, Pullen S. Identifying the critical factors for green construction – an empirical study in China. Habitat Int 2013;40:1–8.
[7] Yuan X, Wang X, Zuo J. Renewable energy in buildings in China – a review. Renew Sustain Energy Rev 2013;24:1–8.
[8] Zhao Z Y, Zuo J, Fan L L, Zillante G. Impacts of renewable energy regulations on the structure of power generation in China – a critical analysis. Renew Energy 2011;36:24–30.
[9] Lim S Y, Lim K M, Yoo SH. External benefits of waste-to-energy in Korea: a choice experiment study. Renew Sustain Energy Rev 2014;34:588–95.
[10] Long H, Li X, Wang H, Jia J. Biomass resources and their bioenergy potential estimation: a review. Renew Sustain Energy Rev 2013;26:344–52.
[11] Pirasteh G, Saidur R, Rahman SMA, Rahim NA. A review on development of solar drying applications. Renew Sustain Energy Rev 2014;31:133–48.
[12] Abuelnuor AAA, Wahid MA, Hosseini SE, Saat A, Saqr KM, Sait HH, et al. Characteristics of biomass in flameless combustion: a review. Renew Sustain Energy Rev 2014;33:363–70.
[13] Adeoti O, Ayelegun TA, Osho SO. Nigeria biogas potential from livestock manure and its estimated climate value. Renew Sustain Energy Rev 2014;37:243–8.
[14] Farrelly DJ, Everard CD, Fagan CC, McDonnell KP. Carbon sequestration and the role of biological carbon mitigation: a review. Renew Sustain Energy Rev 2013;21:712–27.
[15] Liu J, Wang S, Wei Q, Yan S. Present situation, problems and solutions of China's biomass power generation industry. Energy Policy 2014;70:144–51.
[16] U.S. Energy Information Administration. Biomass and Waste Electricity Net Generation; 2014. 〈http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=6&pid=38&aid=12&cid=BR,CH,GM,JA,US,&syid=1992&eyid=2011&unit=BKWH〉.
[17] Tsay MY. A bibliometric analysis of hydrogen energy literature, 1965–2005. Scientometrics 2008;75:421–38.
[18] Garfield E. Is citation analysis a legitimate evaluation tool? Scientometrics 1979;1:359–75.
[19] Beerkens M. Facts and fads in academic research management: the effect of management practices on research productivity in Australia. Res Policy 2013;42:1679–93.
[20] van Raan AF. For your citations only? Hot topics in bibliometric analysis Meas: Interdiscip Res Perspect 2005;3:50–62.
[21] Tsay M y. Knowledge flow out of the domain of information science: a bibliometric and citation analysis study. Scientometrics 2014:1–16.
[22] Du H, Li N, Brown MA, Peng Y, Shuai Y. A bibliographic analysis of recent solar energy literatures: the expansion and evolution of a research field. Renew Energy. 2014;66:696–706.
[23] van Leeuwen T, Costas R, Calero-Medina C, Visser M. The role of editorial material in bibliometric research performance assessments. Scientometrics 2013;95:817–28.
[24] Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci USA 2005;102:16569–72.
[25] Birks Y, Fairhurst C, Bloor K, Campbell M, Baird W, Torgerson D. Use of the *h*-index to measure the quality of the output of health services researchers. J Health Serv Res Policy 2014;19:102–9.
[26] McCarty C, Jawitz JW, Hopkins A, Goldman A. Predicting author *h*-index using characteristics of the co-author network. Scientometrics 2013;96:467–83.
[27] Miroiu A. Axiomatizing the Hirsch index: quantity and quality disjoined. J Informetr 2013;7:10–5.
[28] Jones C, Volpe EH. Organizational identification: extending our understanding of social identities through social networks. J Organ Behav 2011;32:413–34.
[29] Lienert J, Schnetzer F, Ingold K. Stakeholder analysis combined with social network analysis provides fine-grained insights into water infrastructure planning processes. J Environ Manag 2013;125:134–48.
[30] Lee J-Y, Bachrach DG, Lewis K. Social network ties, transactive memory, and performance in groups. Organ Sci 2014;25:951–67.
[31] Du H, Wei L, Brown MA, Wang Y, Shi Z. A bibliometric analysis of recent energy efficiency literatures: an expanding and shifting focus. Energy Effic 2013;6:177–90.
[32] Yaoyang X, Boeing WJ. Mapping biofuel field: a bibliometric evaluation of research output. Renew Sustain Energy Rev 2013;28:82–91.
[33] Stelte W, Holm JK, Sanadi AR, Barsberg S, Ahrenfeldt J, Henriksen UB. A study of bonding and failure mechanisms in fuel pellets from different biomass resources. Biomass Bioenergy 2011;35:910–8.
[34] Stelte W, Nielsen NPK, Hansen HO, Dahl J, Shang L, Sanadi AR. Pelletizing properties of torrefied wheat straw. Biomass Bioenergy 2013;49:214–21.
[35] Naik SN, Goud VV, Rout PK, Dalai AK. Production of first and second generation biofuels: a comprehensive review. Renew Sustain Energy Rev 2010;14:578–97.
[36] Sims RE, Mabee W, Saddler JN, Taylor M. An overview of second generation biofuel technologies. Bioresour Technol 2010;101:1570–80.
[37] Chu S, Majumdar A. Opportunities and challenges for a sustainable energy future. Nature 2012;488:294–303.
[38] Haarlemmer G, Boissonnet G, Imbach J, Setier P-A, Peduzzi E. Second generation BtL type biofuels – a production cost analysis. Energy Environ Sci 2012;5:8445–56.
[39] Kumar P, Barrett DM, Delwiche MJ, Stroeve P. Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. Ind Eng Chem Res 2009;48:3713–29.
[40] Kato DM, Elía N, Flythe M, Lynn BC. Pretreatment of lignocellulosic biomass using Fenton chemistry. Bioresour Technol 2014;162:273–8.
[41] Lin Y, Tanaka S. Ethanol fermentation from biomass resources: current state and prospects. Appl Microbiol Biotechnol 2006;69:627–42.
[42] Nigam PS, Singh A. Production of liquid biofuels from renewable resources. Prog Energy Combust Sci 2011;37:52–68.
[43] Talebnia F, Karakashev D, Angelidaki I. Production of bioethanol from wheat straw: an overview on pretreatment, hydrolysis and fermentation. Bioresour Technol 2010;101:4744–53.
[44] Molino A, Nanna F, Ding Y, Bikson B, Braccio G. Biomethane production by anaerobic digestion of organic waste. Fuel 2013;103:1003–9.
[45] Singh A, Smyth BM, Murphy JD. A biofuel strategy for Ireland with an emphasis on production of biomethane and minimization of land-take. Renew Sustain Energy Rev 2010;14:277–88.
[46] Liu H, Jiang G, Zhuang H, Wang K. Distribution, utilization structure and potential of biomass resources in rural China: with special references of crop residues. Renew Sustain Energy Rev 2008;12:1402–18.
[47] Zervos A, Lins C, Muth J. RE-thinking 2050: a 100% renewable energy vision for the European Union: EREC; 2010.
[48] Bentsen NS, Felby C. Biomass for energy in the European Union-a review of bioenergy resource assessments. Biotechnol Biofuels 2012;5:25.
[49] Meher Kotay S, Das D. Biohydrogen as a renewable energy resource—prospects and potentials. Int J Hydrog Energy 2008;33:258–63.
[50] Show KY, Lee DJ, Tay JH, Lin CY, Chang JS. Biohydrogen production: current perspectives and the way forward. Int J Hydrog Energy 2012;37:15616–31.
[51] Davis F. Higson SPJ. Biofuel cells—recent advances and applications. Biosens Bioelectron 2007;22:1224–35.
[52] Zhang GF, Xie SD, Ho YS. A bibliometric analysis of world volatile organic compounds research trends. Scientometrics 2010;83(2):477–92.
[53] Zhou F, Guo HC, Ho YS, Wu CZ. Scientometric analysisof geostatistics using multivariate methods. Scientometrics 2007;73(3):265–79 [search trends. Scientometrics 83(2), 477–92].
[54] Chen H, Ho YS. Highly cited articles in biomass research: a bibliometric analysis. Renew Sustain Energy Rev 2015:12–20.