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Way forward for alternative energy research: A bibliometric analysis during 1994–2013

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ABSTRACT

The alternative energy plays a crucial role in the sustainable energy development. The alternative energy related literature had attracted a growing attention with the research outputs expanding substantially. Based on the Science Citation Index-Expanded (SCI-E) and the Social Sciences Citation Index (SSCI), a bibliometric analysis of the research output was carried out to depict existing research activities on alternative energy and future directions. The article was the main type of publications with the English as the dominate language to explain their results. With the publications increasing rapidly since 2008, the researches mostly focused on the fields of Energy & Fuels and Environmental Sciences. Energy Policy was the journal that published the largest number of research articles on the alternative energy. The bioenergy and solar energy were popular items in the commonly used 20 journals. Among the countries, the USA was leading on alternative energy related research, publishing the largest number of articles (TP=2368) and being the most influent (*h*-index=90). The USA played a key role in the academic collaborations with China, UK, Canada, Germany, Italy, South Korea and Spain. The National Renewable Energy Lab (the USA) contributed most in the alternative energy field and more specially, the School of Electrical & Computer Engineering (TP=36) was the most productive subordinate in the National Technology University of Athens. It was interesting to note that more attention was paid to solar or wind energy during the first 5 or 10 years, then turned to bioenergy subsequently except for Spain, Canada and Australia. In addition, bioenergy received the most attention in the 7 types of alternative energy. The forest/wood biomass, energy crops and switchgrass were the main bioenergy resources and fermentation was the commonly used conversion technology. The production of biogas, biodiesel and bioethanol was most popular in the bioenergy related studies. Wind energy and solar energy related researches were mainly on the energy utilization approaches such as the wind generation, wind farm, photovoltaic and solar thermal. The conversion devices such as the wind turbine and solar cell were paid most attention in order to improve the production efficiency. The most cited article, published in *Desalination* in 2009 with 1562 citations until 2013, was about wind power utilization in the reverse osmosis desalination plant.

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1. Introduction

The demand for energy is expected to expand continuously, more than tripled by the end of the century [1]. At present, about 80% of the world's energy is supplied by traditional fossil fuels. The combustion of traditional fossil fuels leads to emission of carbon dioxide and other pollutants into the atmosphere, which is responsible for environmental issues such as smog and acid rain [2–4]. There is a growing conflict between fulfilling the energy requirements of sustainable economic development and the reduction of the environmental impacts of fossil fuel combustion. As a result, policy makers, business leaders, consumers and researchers have increasingly turned their attention to the alternative energy sources such as solar, wind, and biomass [5–10]. For example, the Energy Policy for European Countries proposes to achieve a 20% share of renewable energies in the energy mix by 2020 [11]. Indeed, it presents one of the greatest challenges to human beings for the access to safe and clean energy supplies.

Accordingly, with the recognition of importance and availability of technologies for the alternative energy, the associated body of literature has grown substantially. The research related to the alternative energy has become multidisciplinary covering a wide spectrum including studies in energy and fuels [12], environmental sciences [13], environmental studies [14], engineering and chemical [15] and so on. Therefore, it is necessary to evaluate the growing body of literature on the alternative energy. Bibliometric techniques can offer an important quantitative perspective to assess the development and growth of research related to the alternative energy.

Bibliometrics is a set of methods to quantitatively analyze scientific and technological literature [16]. It was defined by Pritchard (1969) as "the application of mathematics and statistical methods to books and other media of communication [17]. Two most common bibliometric methods are citation analysis and content analysis. Bibliometric methods have been widely employed to investigate the impact of research fields, the impact of scholars, and the impact of a particular publication [18]. The bibliometric technique is mainly qualitative by transforming something intangible (scientific quality) into a manageable entity. It has been widely adopted in quantitative research assessment exercises of academic output. Two advantages associated with bibliometric analysis are: (1) it uses indicators and the calculation of certain classical laws to assess the research or the scientific production in a specific area over a period of time; (2) it offers an assessment approach which recognizes the knowledge generation nature of science as a system [19]. Indeed, bibliometric techniques have become an indispensable instrument to measure the scientific progress in various fields [20].

The aim of this study is to quantitatively and qualitatively evaluate the global trend of research literature related to alternative energy from 1994 to 2013. Using bibliometric method, various publication characteristics will be obtained such as publication types, the subject categories, institutions, countries, citation patterns as well as content analysis of keywords and titles. In addition, focus is placed on the development patterns of energy types, e.g. bioenergy, wind energy, solar energy, nuclear energy, geothermal, hydropower, and ocean power in different countries. These results not only provide a better understanding of global hotspots in the research related to the alternative energy, but may also influence researchers' future research directions.

2. Methodology

2.1. The bibliometric method

Bibliometrics is a multifaceted endeavor covering structural, dynamic, evaluative and predictive scientometrics [21]. Used in the field of library and information science initially, it has spread to other areas, especially in the quantitative research assessment exercises of academic outputs aiming at evaluating the impact of the researchers, the institutions and so on. Containing the most extensive quantitative analysis of science, bibliometric method is an effective method of quantitative analysis method to measure the contribution of different aspects within a given topic [22–24]. It offers a useful tool to shift from micro (scientist and institute) level to macro (national and global) level. Furthermore, the research trends and popular issues at the present, past or future can be identified by means of the bibliometrics analysis [25]. In this paper, many quantitative characteristics of science were obtained by employing the bibliometric method, such as publication counts of the journals and the subject categories.

2.2. The social network analysis

The social network is a set of people or groups each of which has connections with others. The people or groups, and the connections are called "actors" and "ties", respectively [26]. Collaboration is a common social interaction which includes many actors and relationships between them. The social network analysis (SNA) method has been widely employed in various fields where the social network is visualized from a statistical and mathematical perspective [27]. In the SNA, a square array of measurements is used to represent the network [28]. Similarly, it is suggested to measure the strength of collaborative ties based on the distance calculation [29].

Among various software tools, the UCINET containing Netdraw and Pajek is used frequently in the SNA for the visualization of networks and the mathematical calculation, respectively [28]. In addition, bibexcel is another software tool to perform several bibliometric and network analysis [30].

In this study, the SNA was undertaken to analyze the academic collaboration among different countries and institutes by using the bibexcel and Pajek.

2.3. The impact factor (IF) and the h-index

Proposed by Garfield in *Science* in 1955, an impact factor is a standardized indicator created by the Institute of Scientific Information (ISI) to measure the way a journal receives citations to its articles over time [31,32]. The value of impact factor is calculated by means of dividing the number of current citations a journal receives to its articles published in last two years by the number of articles been published during the same period of time [32]. The impact factor has been frequently employed to measure the quality of a journal, research papers or researchers. In the following analysis, the impact factor 2013 (IF 2013) from the ISI Journal Citation Reports (JCR) was employed to evaluate the quality of journals.

The *h*-index was proposed by Hirsch [33] to characterize the scientific output of a researcher or organization. The *h*-index was defined as "a scientist has index *h* if *h* of his/her *N* papers have at least *h* citations each, and the other $(N-h)$ papers have fewer than *h* citations each" [34]. The *h*-index thereby takes both the quantity (number of publications) and quality (number of citations) of the scientist into account at the same time [35]. Since then, it has been widely applied in the physics community and scientometrics studies [34]. It offers an objective indicator for impact of a scientist or journal [19]. In the following analysis of journals, the institutes and the countries, the *h*-index was calculated to evaluate their level of achievements.

3. Results

The publications considered in this paper were collected from the Science Citation Index-Expanded and the Social Sciences Citation Index, which provided a ready data resource for the bibliometrics analysis. The keywords "renewable energ*" and "sustainable energ*" were used to search the titles, abstracts and keywords within the timeframe from 1994 to 2013. As a result, 14,902 publications were obtained.

3.1. The publication types and the languages

Of all publications retrieved from the database, the article accounted for 81.63%, followed by review (12.98%), proceedings paper (8.58%), and others (e.g. editorial material, news item, meeting abstract and book review). Therefore, only article type of publications

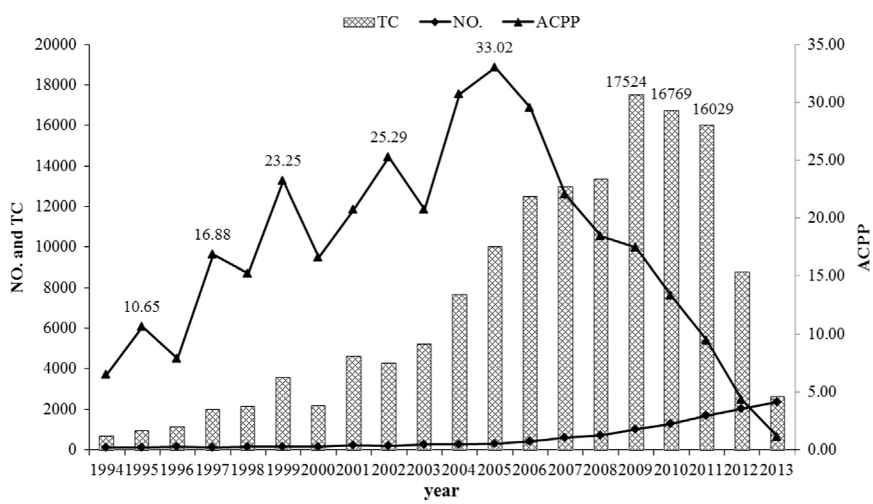

Fig. 1. The publication output performance.

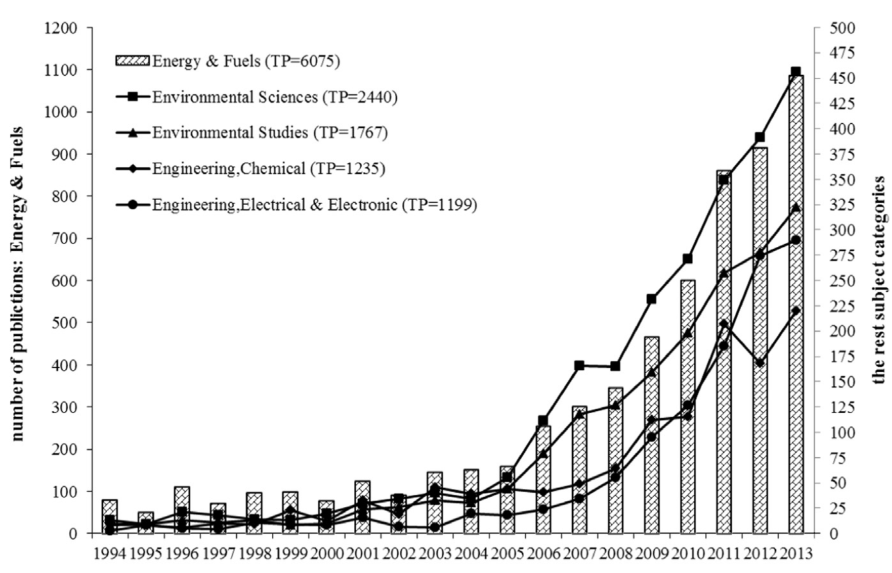

Fig. 2. The top five subject categories. TP: The total number of publications.

would be further analyzed. Similarly, English (95.73%) was the most frequently used language, followed by the Germany (1.91%), Polish (0.66%), Spanish (0.45%) and so on.

As shown in Fig. 1, first, the number of articles (NO.) increased slowly in the first 14 years and then dramatically during 2008–2013. The articles published in last five years accounted for 74% of the total amount of articles. Second, the annual total citations of articles (TC) grew constantly, and reached the peak during 2009–2011. Third, the average citations per year (ACPP) fluctuated with high figures in 1995, 1997, 1999, 2002 and 2005 but decreased dramatically during 2006–2013. This was probably due to a higher number of publications but with a relatively lower number of citations.

3.2. The distribution of subject categories

The 12,164 articles covered a total of 177 subject categories in SCI-E and SSCI. The top five subject categories would be further analyzed (Fig. 2). As shown in Fig. 2, the publications of the top five subject categories grew rapidly since 2004 where Energy and Fuels had been in a leading position in last two decades. Based on the category descriptions, Energy and Fuels covers resources on the development, production, use, application, conversion, and management of nonrenewable fuels (e.g. coal, petroleum, and gas) and renewable energy sources (e.g. solar, wind, biomass, geothermal, hydroelectric), however excludes resources dealing with nuclear energy and nuclear technology [36]. Nevertheless, the categories related to environment (e.g. Environmental Sciences, Environmental Studies) had gained more attention than Engineering, Chemical or Engineering, Electrical & Electronic in the alternative energy field from 1994 to 2013.

3.3. The journals' performance

The publication distribution of the top 20 most productive journals, accounting for 43.1% of the total publications, was shown in Table 1. This indicated the breadth of publication distribution as well as the broad interest in alternative energy research from

Table 1
The performance of top 20 most productive journals.

Journal name	TP[a] (%[b])	IF 2013[c]	*h*-Index
Energy Policy	1288(10.59)	2.696	52
Renewable Energy	1000(8.22)	3.361	46
Energy	452(3.72)	4.159	35
International Journal of Hydrogen Energy	333(2.74)	2.930	37
Applied Energy	319(2.62)	5.261	33
Biomass & Bioenergy	260(2.14)	3.411	34
Energy Conversion and Management	242(1.99)	3.590	31
Desalination	148(1.22)	3.960	22
Solar Energy	142(1.17)	3.541	25
Energy and Buildings	130(1.07)	2.465	22
Journal of Power Sources	106(0.87)	5.211	29
Journal of Cleaner Production	101(0.83)	3.590	19
Journal of Renewable and Sustainable Energy	96(0.79)	0.925	5
Bioresource Technology	96(0.79)	5.039	27
Energy Economics	94(0.77)	2.580	15
IEEE Transactions on Industrial Electronics	93(0.76)	6.500	32
Energy Sources Part A—Recovery Utilization and Environmental Effects	93(0.76)	0.358	10
International Journal of Energy Research	87(0.72)	2.737	15
IEEE Transactions on Power Systems	81(0.67)	3.530	17
IEEE Transactions on Power Electronics	81(0.67)	5.726	23

[a] TP: the total publications of the journal during 1994–2013.
[b] %: The percentage of the publications of the journal.
[c] IF 2013: the journal's impact factor in 2013.

Table 2
The top 10 most productive countries' performances.

Country	TP[a]	TP R (%)[b]	SP R (%)[c]	CP R (%)[d]	FP R (%)[e]	RP R (%)[f]	C (%)[g]	*h*-Index
USA	2368	1(19.9)	1(17.63)	1(30.26)	1(16.93)	1(16.84)	27.32	90
UK	1174	2(9.87)	2(8.39)	2(16.6)	2(8.31)	2(8.37)	30.24	50
Germany	911	3(7.66)	3(6.26)	3(14.03)	3(6.25)	3(6.23)	32.93	41
China	749	4(6.29)	5(4.67)	4(13.7)	4(5.19)	4(5.22)	39.12	37
Turkey	628	5(5.28)	4(5.75)	20(3.13)	5(5.08)	5(5.10)	10.67	47
Spain	571	6(4.80)	6(3.87)	5(9.03)	6(4.06)	6(4.06)	33.80	34
Italy	531	7(4.46)	7(3.72)	8(7.86)	7(3.69)	7(3.77)	31.64	38
Canada	473	8(3.98)	10(2.97)	6(8.56)	8(3.07)	8(3.1)	38.69	41
Australia	444	9(3.73)	9(3.13)	10(6.45)	9(3.00)	9(3.04)	31.08	32
Japan	396	10(3.33)	12(2.67)	11(6.31)	11(2.67)	11(2.66)	34.09	29

[a] TP: The total number publications of one country during 1994–2013.
[b] TP R (%): Rank and the percentage of total publications.
[c] SP R (%): Rank and the percentage publications without international collaborations.
[d] CP R (%): Rank and the percentage of publications with international collaborations.
[e] FP R (%): Rank and the percentage of first-author country publications.
[f] RP R (%): Rank and the percentage of corresponding-author country publications.
[g] C (%): The number of internationally collaborative publications and the percentage of the internationally collaborative publications of one country.

various perspectives. As shown in Table 1, the journals' performance in terms of *h*-index was consistent with the impact factor (IF). The journals with the higher IF tended to have a relatively higher *h*-index. For example, Applied Energy's IF was 5.261 with the *h*-index of 33. Similarly, the journal with a higher *h*-index was normally associated with a relatively higher IF. Energy Policy had the highest *h*-index (52) as well as a relatively high IF (2.696). However, it was not necessary that the journal with a low *h*-index would have a low IF, e.g. International Journal of Energy Research (*h*-index, 15; IF 2013, 2.737), IEEE Transactions on Power Systems (*h*-index, 17; IF 2013, 3.530) and Journal of Cleaner Production (*h*-index, 19; IF 2013, 3.598). In addition, according to the titles and themes of the 20 journals, the "bioenergy" (Biomass & Bioenergy, Bioresource Technology) and "solar energy" (Solar Energy) were paid most attention in various types of alternative energies.

3.4. The characteristics of the countries

3.4.1. The countries' performance

As shown in Table 2, less than 18% of 11,899 publications with authors' addresses involved international collaborations. The USA, accounting for 19.90% of all the publications was the most productive country with respect to total publications, publications without international collaborations, publications with international collaborations, and the first-author country. Furthermore, the USA was the most academically influential country with the highest *h*-index (90). Compared to the USA, China ranked 8th with respect to *h*-index (37) though it had published a large number of articles. This showed that China was an academically productive country however with relatively weaker influence. By contrast, Turkey and Canada ranked 3rd and 5th in terms of *h*-index, and 5th and 8th with respect to total publications, respectively.

The number of publications per year of top 6 productive countries was shown in Fig. 3. The publications of these six countries increased rapidly since 2006 and the USA had always been in a leading position during 1994–2013. China exceeded UK and Germany to rank 2nd in 2013. This implied that alternative energy has attracted an increasing level of attention in China in recent years.

3.4.2. The academic cooperation

The academic collaborative relationships among the 25 most productive countries were shown in Fig. 4. It showed that the USA, in the central position, cooperated frequently with China, UK, Canada,

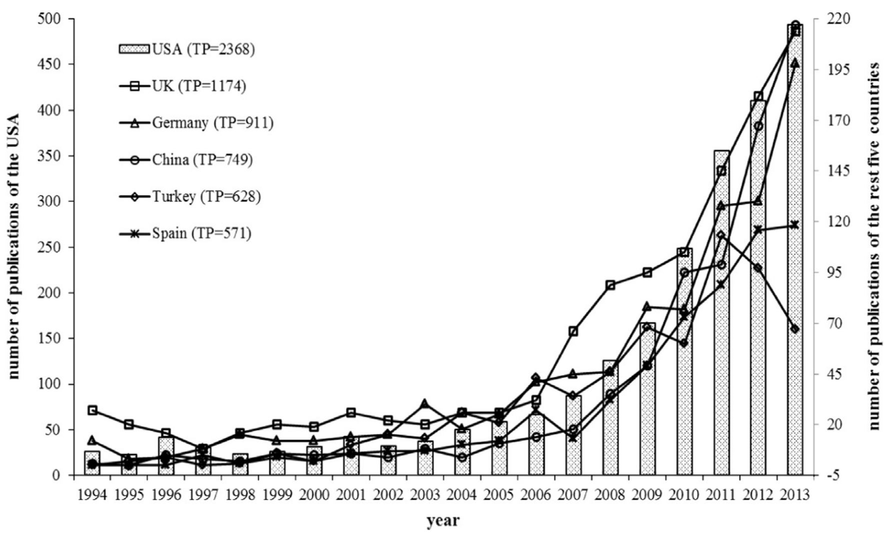

Fig. 3. The output of the six most productive countries. TP: The total number of the country's publications.

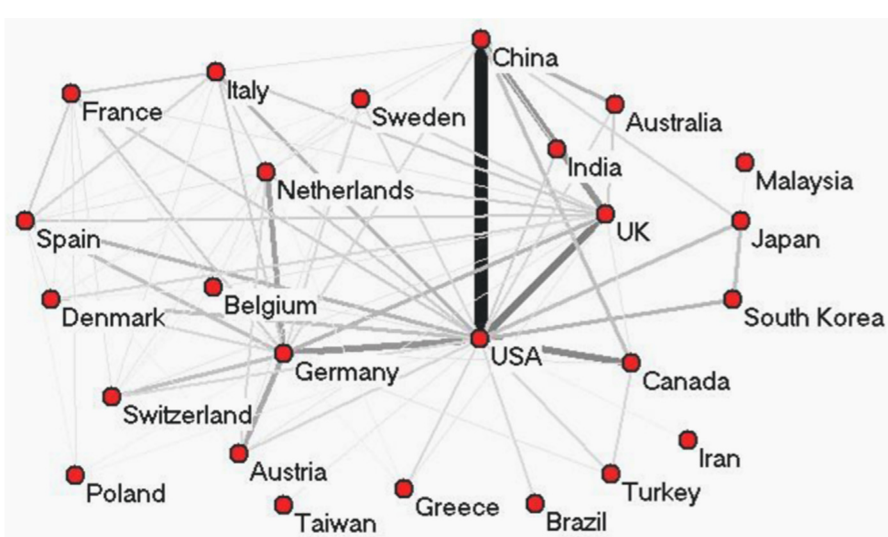

Fig. 4. The academic collaborative relationships among the top 25 most productive countries. *Note*: The lines between two countries stand for their cooperation relationship; and the thicker the line is, the stronger the collaboration is.

Germany, Italy, South Korea and Spain, with 100, 56, 54, 47, 33, 32 and 30 cooperative publications, respectively. In addition, Germany showed a close collaborative relationship with other countries such as Netherlands, Austria and UK. Similarly, the cooperation between China and UK was outstanding as shown in Fig. 4 with 45 joint publications. The results also clearly indicated that the countries ranking higher with respect to total publications tended to have more academic cooperation with other countries.

3.4.3. *Alternative energy development features*

Table 3 showed the main types of alternative energy development covered by publications from the top 10 countries in an interval of five years. It can be observed that bioenergy, solar energy and wind energy were the three major types of alternative energy among most countries, no matter the level of economic development. Bioenergy, solar energy and wind energy accounted for a larger share of the total publications than nuclear power or other energy types. Except for the Spain, Canada and Australia, most countries had paid more attention on solar or wind energy during the first 5 or 10 years, but turned to bioenergy subsequently.

However, publications related to other energy types have been developed in various levels during different periods of time. For instance, hydropower related literature grew substantially in developed countries such as the USA, UK, Spain, Italy, Canada, Australia and Japan, and in developing countries like China and Turkey. The hydropower was paid more attention during the next 15 years in these countries expect for Italy and Australia. The advancement of technologies related to these types of alternative energies helped them to fulfill the energy demand to a certain degree.

There were several factors affecting the different focus of alternative energy development, e.g. geographical conditions, level of economic development as well as the availability of natural resources. For instance, Turkey was one of first batch of countries in the world utilizing geothermal energy directly arguably due to the large geothermal energy resources available and the fiscal support from the government [37,38].

Table 3
The development of the alternative energy in the top 10 most productive countries.

Country	94–98		99–03		04–08		09–13	
	Energy[a]	%[b]	Energy[a]	%[b]	Energy[a]	%[b]	Energy[a]	%[b]
USA	Bio[c]	27.63	Bio	20.79	Bio	21.63	Bio	21.51
	Solar[d]	15.79	Wind[e]	14.85	Wind	14.18	Wind	13.96
	Wind	7.89	Solar	7.92	Solar	13.48	Solar	12.81
	Geo[f]	6.58	Hydro[g]	2.97	Nuclear[h]	1.77	Ocean[i]	1.53
UK	Bio	19.51	Bio	28.40	Bio	13.09	Bio	14.55
	Solar	19.51	Solar	14.81	Wind	12.57	Wind	14.09
	Wind	19.51	Wind	11.11	Solar	7.33	Solar	8.03
	Ocean	2.44	Nuclear/hydro	4.94	Ocean	4.71	Ocean	3.79
Germany	Solar	40.00	Solar	60.00	Bio	20.31	Bio	20.28
	Bio	26.67	Bio	40.00	Solar	18.75	Solar	10.83
	Geo	13.33	Wind	26.67	Wind	7.81	Wind	8.86
	Wind	6.67			Geo	2.34	Geo	1.97
China	Solar	20.00	Bio	18.18	Bio	27.54	Bio	16.70
			Solar	9.09	Solar	24.64	Solar	11.63
	Bio	20.00	Wind/ocean	4.55	Wind	4.35	Wind	11.07
							Hydro	1.31
Turkey	Geo	40.00	Bio	34.15	Bio	26.28	Bio	22.86
	Bio/solar/wind	20.00	Wind	21.95	Geo	17.31	Wind	14.82
			Ocean/solar	17.07	Wind	15.38	Solar	14.07
			Geo/hydro	14.63	Solar	13.46	Hydro	4.27
Spain	Solar	33.33	Bio /solar	25.00	Solar	29.89	Solar	18.90
					Wind	22.99	Wind	16.03
			Wind	15.00	Bio	13.79	Bio	14.59
					Hydro	3.45	Geo	1.20
Italy	Solar	28.57	Bio	13.33	Bio	22.73	Bio	25.27
	Wind	21.43			Solar	21.21	Solar	18.01
	Bio	14.29	Solar/geo	6.67	Wind	6.06	Wind	8.06
	Hydro/geo	7.14					Geo	2.15
Canada	Bio	46.15	Bio	32.00	Wind	17.65	Wind	15.50
			Solar	20.00	Hydro	9.41	Bio	14.59
	Solar	15.38	Wind	12.00	Bio/solar/geo	7.06	Solar	10.33
			Geo/hydro	4.00	Ocean	4.71	Hydro/geo	2.13
Australia	Solar	23.53	Bio	17.65	Bio	19.05	Solar	18.89
	Wind	17.65			Solar	14.29	Wind/bio	14.07
	Geo/hydro/ocean	5.88	Solar	11.76	Wind	6.35	Geo	1.85
					Nuclear	1.59	Ocean	1.48
Japan	Nuclear	9.09	Bio	17.24	Wind	18.31	Bio	16.30
			Solar/hydro	13.79	Bio	14.08	Solar	14.10
			Wind	10.34	Solar	8.45	Wind	7.93
			Geo	6.90	Nuclear/hydro	2.82	Nuclear	4.85

[a] Energy: the main energy type of one country in each 5 years.
[b] %: The percentage of the energy type in each 5 years.
[c] Bio: bioenergy.
[d] Solar: solar energy.
[e] Wind: wind power.
[f] Geo: geothermal.
[g] Hydro: hydropower.
[h] Nuclear: nuclear power.
[i] Ocean: ocean power.

Nuclear power provided an alternative energy source to counteract the environmental issues associated with the traditional fossil fuels. However, the nuclear energy development was controversial due to safety concerns particularly the occurrence of the Chernobyl accident (1986) and Fukushima plant disaster in Japan (2011). Nuclear power received more attention in recent 10 years in Japan, the USA and Australia. For example, it is still under debate in Japan whether to restart its idled reactors after the Fukushima nuclear accident. Even though the public is favor of phasing out nuclear energy, the government policy holds much uncertainty [39].

3.5. The characteristics of the institutes

3.5.1. The institute's performance

The articles (11,899) with authors' addresses were published by a wide range of institutes (6774), in which 56.17% of articles were published independently. The performance of the top 10 productive institutes was shown in Table 4.

Among the top ten institutions, two came from the USA, Denmark and China each. There were no institutes from Spain, Italy, Canada, Australia and Japan, each of which ranked in the top 10 productive countries. National Renewable Energy Lab ranked the 1st with respect to total publications, sole institute publications, internationally collaborative publications, the first-author institute publications and corresponding-author institute publications. National Renewable Energy Lab also had the highest *h*-index (29), which indicated its great academic influence in the field of alternative energy research. In spite of been ranked 2nd in terms of the total publications, the Chinese Academy of Sciences only ranked 5th according to the *h*-index. This showed a relatively weaker influence of this institute. On contrary, University of Aalborg and Ege University ranked 10th and 9th according to total publications, but ranked 2nd and 3rd in terms of *h*-index, respectively.

Furthermore, the top subordinates of the top 3 institutes were analyzed, which published no less than 5 articles (see Table 5). Considering subordinates publishing more than 10 publications, the Chinese Academy of Science and the National Technical University of Athens had 2 and 3 subordinates, respectively. For the National Renewable Energy Lab, National Bioenergy Centre was outstanding with 9 publications compared to the other two subordinates. In the Chinese Academy of Sciences, Graduate School of the Chinese Academy of Sciences and Institute of Engineering Thermophysics were more productive than other subordinates, which published 20 and 12 articles, respectively. Similarly, the School of Electrical and

Table 4
The performances of the top 10 most productive institutes.

Institution name	TP[a]	TP R (%)[b]	SP R (%)[c]	CP R (%)[d]	FP R (%)[e]	RP R (%)[f]	C (%)[g]	*h*-Index
National Renewable Energy Lab, USA	166	1(1.4)	1(1.03)	1(1.86)	1(0.92)	1(0.88)	58.43	29
Chinese Academy Sciences, China	120	2(1.01)	10(0.48)	2(1.69)	2(0.68)	2(0.67)	73.33	18
National Technology University of Athens, Greece	90	4(0.76)	3(0.78)	8(0.73)	5(0.55)	5(0.53)	42.22	19
Indian Institute of Technology, India	87	5(0.73)	2(0.87)	18(0.56)	3(0.63)	3(0.58)	33.33	17
Technical University of Denmark, Denmark	83	6(0.70)	7(0.61)	7(0.81)	6(0.54)	7(0.52)	50.60	17
Tsinghua University, China	83	6(0.70)	12(0.45)	4(1.02)	7(0.52)	6(0.52)	63.86	15
University of California Berkeley, USA	78	7(0.66)	15(0.42)	4(0.96)	10(0.45)	11(0.41)	64.10	16
The Imperial College of Science, Technology and Medicine, UK	77	8(0.65)	17(0.4)	5(0.96)	12(0.39)	12(0.40)	64.94	18
Ege University, Turkey	70	9(0.59)	8(0.55)	12(0.63)	9(0.49)	8(0.48)	47.14	21
University of Aalborg, Denmark	67	10(0.56)	9(0.52)	14(0.61)	11(0.4)	11(0.41)	47.76	29

Note: Since there were kinds of different name forms for one institute, we calculated them together. For example, Natl Renewable Energy Lab, USA, NREL, USA, Natl Wind Technol Ctr, USA et al. were added up to Natl Renewable Energy Lab, USA.

[a] TP: The total number publications of one institute in 1994–2013.
[b] TP R (%): Rank and the percentage of total publications.
[c] SP R (%): Rank and the percentage of single institute publications.
[d] CP R (%): Rank and the percentage of internationally collaborative publications.
[e] FP R (%): Rank and the percentage of first-author institute publications.
[f] RP R (%): Rank and the percentage of corresponding-author institute publications.
[g] C (%): The number of internationally collaborative publications and the percentage of the internationally collaborative publications of one institute.

Table 5
The top subordinates of the top 3 institutes in the alternative energy area.

Institution	Subordinate	TP[a]
National Renewable Energy Lab, USA	National Bioenergy Centre	9
	National Wind Technology Centre	8
	Bioscience Centre	5
Chinese Academy Sciences, China	Graduate School (Graduate University)	20
	Institute of Engineering Thermophysics	12
	Institutional Geographic Sciences & Natural Resources Research	8
	Institute of Process Engineering	8
	Institute of Electrical Engineering	8
	Institute of Urban Environment	6
	Dalian Institute of Chemical Physics	5
	Eco-Environment Science Research Center	5
	Institute of Policy & Management	5
National Technology University of Athens, Greece	School of Electrical & Computer Engineering	36
	School of Chemical Engineering	18
	School of Mechanical Engineering	13

[a] TP: The total number publications of one subordinate in 1994–2013.

Computer Engineering had 36 publications under the institute National Technical University of Athens, followed by the School of Chemical Engineering (18) and the School of Mechanical Engineering (13).

3.5.2. The academic cooperation

The academic collaborative relationships among the top 30 institutes were shown in Fig. 5. It showed that National Renewable Energy Lab and Texas A&M University had the closest collaborative relationship with 5 joint publications. In addition, Technical University of Denmark cooperated a lot with University of Aalborg, Stanford University, the Imperial College of Science, Technology and Medicine as well as University of California Berkeley. It can be observed that the institutes tended to collaborate more with those within the same country than international counterparts. This pattern was shown in various institutes such as Delft University of Technology and University of Utrecht of Netherlands, University of California Berkeley and National Renewable Energy Lab of USA, Tsinghua University and Chinese Academy Sciences of China.

3.6. Hot issues

3.6.1. The hot issues about different types of alternative energy

Li et al. suggested combining analysis of keywords, article title, keywords plus and abstracts [40]. By grouping single words and congeneric phrases into categories, historical development of the science can be analyzed more accurately so as to identify the hot issues of alternative energy related literature.

According to the data analysis, 7 types of alternative energy frequently covered in the literature could be grouped into two categories: the one including bioenergy, solar energy, wind energy, which attracted more attention; and the other containing hydropower, geothermal energy, nuclear energy and the ocean power (Table 6).

A large proportion of 2825 bioenergy related articles placed focuses on the biomass resources (e.g. forest/wood biomass, energy crops and switchgrass), the biomass utilization technologies (e.g. fermentation and gasification) and the biomass products (e.g. biogas, biodiesel, bioethanol and bio-oil). Forest or wood biomass has become a main approach to achieve the renewable

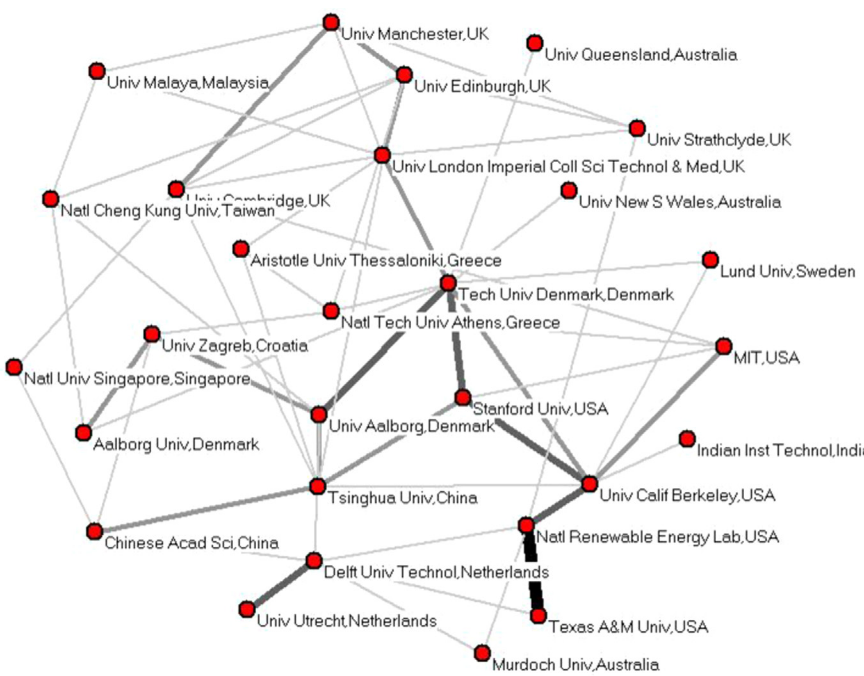

Fig. 5. The academic collaborative relationships among the top 30 most productive institutes. *Note*: The lines between two institutes stand for their cooperation relationship; and the thicker the line is, the stronger the collaboration is. Two institutes were missed for their no collaboration relationships with the other 28 institutes.

Table 6
The hot issues about alternative energy types.

Main topic	TP[a]	Main topic	TP[a]	Main topic	TP[a]
Bioenergy (biomass)	**2825**	**Wind energy**	**1931**	**Solar energy**	**1908**
Biogas	362	Wind turbine	374	Photovoltaic	810
Biodiesel	338	Wind farm	179	Solar radiation	158
Forest/wood biomass	176	Wind generation	103	Desalination	134
Fermentation	157	Wind speed	61	Solar cells	131
Bioethanol	115	Distributed generation	53	Solar thermal	92
Energy crops	77				
Biohydrogen	71				
Bio-oil	63				
Gasification	62	**Hydropower**	**298**	**Geothermal energy**	**220**
Switchgrass	61	**Nuclear energy**	**216**	**Ocean power**	**127**

[a] TP: total publications. It's an aggregation of words with the similar meaning.

energy goals and to fulfill the obligations in Croatia and Serbia according to the Kyoto Protocol, so as to different energy crops like willow in Poland [41,42]. Biomass such as forest biomass, switchgrass and straw had been combusted as energy directly without chemical processing particularly in rural area of developing countries. Nowadays, bioenergy research was mainly concentrated on thermochemical, biological or chemical conversion processes [43]. Fermentation covered in 157 articles was the technology of converting energy crops to biofuels or bioproducts. The related technologies have been improved such as from submerged-state processes to solid-state fermentation processes for the bioprocessing of switchgrass to ethanol and acetate [44]. Biogas (349) had also attracted a growing attention because of its significant advantages such as easily produced as well as stored. Biogas could replace fossil fuels in the transport sector apart from electricity and heat generation [45]. Biodiesel (288) derived from microalgae especially the oilgae conversion processes had been widely accepted from 2008 due to the potential to fulfill the large demand of petroleum [46].

The wide utilization of wind power mainly paid attention to wind farm (179) and wind generation (103), with a large development scale and commercial prospects. These studies focused on the layout of the wind farm to improve the power generation efficiency [47,48]. Wind turbine (374) was certainly a major field of wind power related studies, which paid closer attention to enhancing the production efficiency and the capability to capture a wide range of wind speeds (61) [49]. This was one of most critical issues in the wind power generation. Furthermore, with the power sector continuously reforming on both technological innovation and regulatory changes, viable small-scale distributed generation emerged especially for rural areas and isolated islands. The wind power, one of the distributed generation (53) technologies was cost effective and provided an alternative energy option with significant CO_2 emission reduction potential [50].

Similarly, more attention was paid to the research on "solar energy". The articles related to solar energy increased sharply from 19 in 1994 to 425 in 2013. As the first choice of power source in remote locations due to its environmental benefits and resource richness, photovoltaic (810) was now being developed for the connection to the local grid [51]. A large number of studies have been undertaken on the design of feed-in tariffs scheme. Technology of desalination (134) had attracted a growing attention during last two years, and most of related articles were published by journal *Desalination*. Two distinct technologies were involved, i.e. energy conversion and desalination systems [52]. Solar cell (131) was an electrical device that converted the energy of light directly into electricity by the photovoltaic effect. Solar cell related technologies were improved continuously for its electricity production efficiency and cost reduction [53]. Compared to the conventional energy, however, the renewables such as solar power was not an economical option due to the high capital cost [54].

Other types of alternative energy such as hydropower, geothermal energy, ocean power and nuclear energy received much less attention during the last two decades.

3.6.2. The most cited articles

The variation of annual citations could be used to track the impact of the publications. Although miscounting citations may occur occasionally, the main patterns and the trace of research hot spots remained in data [40]. Table 7 displayed the most frequently cited articles in each year from 1994 to 2013.

Table 7
The most cited articles in each year from 1994 to 2013.

PY[a]	TC[b]	C/Y[c]	Article/Journal	Author[d]	Country[e]
1994	100	5.0	Desalination in Israel—emerging key component in the regional water-balance formula/Desalination	Livnat, A	Taiwan
1995	132	7.0	Barriers to dissemination of renewable energy technologies for cooking/Energy Conversion and Management	Quadir, SA	India
1996	155	8.6	1997: BMBF expenditures for energy research/ATW—International Zeitschrift Fur Kernenergie	–	–
1997	280	16.5	What nuclear power can contribute/ATW—International Zeitschrift Fur Kernenergie	Schwarz, D	Germany
1998	211	13.2	A new statistical distribution function sensitive to renewable energy systems/Electric Machines and Power Systems	Abdelaziz, AR	USA
1999	816	54.4	Improving viability of renewable energy beckons petroleum firms' investment/Oil & Gas Journal	Knott, D	–
2000	201	14.4	An engineering model for heating energy and emission assessment—the case of North Karelia, Finland /Applied Energy	Snakin, JPA	Finland
2001	281	21.6	Renewable sources of energy: state of the art and development perspective/Comptes Rendus De L Academie Des Sciences Serie It Fascicule A-Sciences De La Terre Et Des Planetes	Bal, JL	France
2002	340	28.3	Hydrogen production by cyanobacteria in an automated outdoor photobioreactor under aerobic conditions/ Biotechnology and Bioengineering	Tsygankov, AA	Russia, UK
2003	475	43.2	Foundations for offshore wind turbines/Philosophical Transactions of the Royal Society of London Series A—Mathematical Physical and Engineering Sciences	Byrne, BW	UK
2004	664	66.4	European initiatives for hydrogen based energy systems/ATW—International Journal for Nuclear Power	Forsstrom, H	Belgium
2005	1391	154.6	Thermoeconomic analysis of wind powered seawater reverse osmosis desalination in the Canary Islands/Desalination	Remero-Ternero, V	Spain
2006	1239	154.9	Demonstrated fossil-fuel-free energy cycle using magnesium and laser/Energy & Fuels	Yabe, T	Japan
2007	384	54.9	Role of thermochemical conversion in livestock waste-to-energy treatments: obstacles and opportunities/Industrial & Engineering Chemistry Research	Cantrell, K	USA
2008	399	66.5	Effects of pH conditions on the biological conversion of carbon dioxide to methane in a hollow-fiber membrane biofilm reactor (Hf-MBfR)/Desalination	Ju, DH	South Korea
2009	1562	312.4	Investigation of different operational strategies for the variable operation of a simple reverse osmosis unit/Desalination	Pohl, R	Germany
2010	325	81.3	Finding stable cellulase and xylanase evaluation of the synergistic effect of pH and temperature/New Biotechnology	Farinas, CS	Brazil
2011	437	145.7	Solar hydrogen-producing bionanodevice outperforms natural photosynthesis/Proceedings of the National Academy of Sciences of the United States	Lubner, CE	USA, Germany
2012	207	103.5	Electrochemical characterization of a super capacitor flow cell for power production from salinity gradients/ Electrochimica Acta	Sales, BB	Netherlands
2013	43	43.0	Freestanding three-dimensional graphene/MnO_2 composite networks as ultra light and flexible super capacitor electrodes/ACS Nano	He, YM	China

[a] PY: The year.
[b] TC: The total citations of the article.
[c] C/Y: The average citations of the article.
[d] Author: The first author.
[e] Country: The country of all the authors including the corresponding author.

The articles mainly concentrated on the fields of wind power, hydrogen and bioenergy. The USA, UK and Germany, in a leading place in alternative energy research, published 3, 2 and 3 of those frequently cited articles, 2 of which involved international collaboration.

The most frequently cited article during the last two decades was "Investigation of different operational strategies for the variable operation of a simple reverse osmosis unit", which was published in *Desalination* in 2009 and had been cited 1562 times until 2013. It also has the highest average citations from 1994 to 2013. This paper showed that how a reverse osmosis desalination plant with a wind power supply system was technically feasible under different operational strategies, which helped to promote the wind power utilization in the daily life [55].

4. Conclusions

Based on the data from Science Citation Index-Expanded and the Social Sciences Citation Index, the characteristics such as the publication outputs, subject categories, journal performance and hot issues of the alternative energy related literature were analyzed via the bibliometric technique. Results revealed that scientific outputs of the alternative energy field experienced a substantial growth with growing number of publications as well as the annual total citations of articles. Among the 177 subject categories, Energy & Fuels was the major focus of the existing body of literature, accounting for more than 50% of articles. Moreover, the study categories related to the environment were more popular than Engineering, Chemical or Engineering, Electrical & Electronic. The most commonly used 20 journals were responsible for more than 40% of the total alternative energy articles, in which Energy Policy was the most productive journal with the highest academic influence. The relationship between *h*-index and impact factor showed a certain level of consistency with the journal's performance. In addition, results showed that the bioenergy and solar energy gained more attention in the alternative energy field.

At the global scale, the USA was the most productive and academic influent far ahead of other countries, such as UK, Germany, China and Turkey. The publication outputs of the top six countries achieved a rapid growth since 2006, with China exceeding UK in 2013 as the 2nd ranked. However, China was not equally academically influential in terms of *h*-index. Furthermore, the social network analysis showed that the USA was in the central position in terms of academic cooperation in the field of alternative energy. The results clearly indicated that the countries ranking higher with respect to total number of publications tended to be more active in terms of academic cooperation with other countries. At the institutional scale, National Renewable Energy Lab (USA) was the most productive institution, followed by the Chinese Academy Sciences (China) and National Technology University of Athens (Greece). More specifically, the subordinate analysis showed that the Chinese Academy of Science had the most subordinates working on the alternative energy field in the top 3 institutions. The analysis of the country's alternative energy development showed that bioenergy, solar energy, wind energy attracted more attention compared to other energy types.

Similarly, hot issues in the seven alternative energy types were analyzed to provide a reference for future research endeavors. Bioenergy related studies placed more focuses on the biomass resources such as forest biomass, energy crops and switchgrass. Due to the biological nature, the fermentation was the commonly used conversion technology to produce bio-products. Similarly, the most popular bio-products covered in the related literature were biogas, biodiesel, bioethanol and bio-oil. As one of the most promising technologies for the distributed generation, wind power was a hot theme in the alternative energy related literature where more attention was paid to wind turbine and wind speed with an aim to enhance the electricity generation efficiency. Solar energy was a promising alternative energy especially in remote locations. The photovoltaic and solar thermal were major ways of utilization of solar power. Solar cell, as an important device to convert the solar energy to electricity, received more attention in the solar energy field due to its high cost and inefficiency. Finally, it was interesting to note that the most frequently cited article on alternative energy during the last decade was about utilization of wind power.

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