International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.11 No.09, pp 125-134, 2018

Comparative Analysis between Solar Energy and Wave Energy: Bibliometric Study

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Abstract : This article presents an analysis of trends and the state of research into the main renewable energy sources based on information obtained from the SCIE / SSCI database for the period 2007-2017. This study is aimed at comparing solar and wave energy sources with the aim of comparing their global economic, research and industrial impacts. The results generated from the bibliometric techniques used made it possible to obtain the performance of the production of publications, as well as the influence of different institutions and countries on this subject. Of the 8,172 publications in this bibliometric study, 62.3% refer to solar energy and 37.7% to wave energy, where the United States has been the most influential country in research in this area, presenting the largest volume of publications in both energy sources. The results of this paper provide researchers with an overview of the scope of renewable energy research around the world. In addition, for mastering the subject and its application, relevant data are presented on the countries producing these renewable energies and their relationship with the production of publications, determining the influence that research has on the technological and economic growth of a country.
Keywords : Renewable energies, solar energy, wave energy, bibliometrics.

1. Introduction

With the increasing demand for energy and the emergence of climate change, the development and advancement of renewable energy has become a top priority for all countries[1,2]. Due to this energy and environmental situation, the need for education and training in renewable energies at all levels, especially the energies analyzed in this article, is recognized worldwide[3]. Over the past three decades, many countries have initiated academic programs on renewable energy technologies and related issues[4].

DOI= http://dx.doi.org/10.20902/IJCTR.2018.110916

Mitigation of global energy demand is a very important factor in these modern times, where the development and application of solar energy has made it possible to address this problem in many countries[5], achieving technological and social development in society[6]. Many of these applications came about because of research, authors who thought that photovoltaic solar energy could provide more energy in the future compared to other renewable energies[7], and applied this knowledge to make solar energy the most productive in the world[8]. In the last decade, research and development of photovoltaic solar energy has been supported by central and state governments[9].

Renewable energy, especially its new forms, represents a unique solution to ensure the sustainable development of society[10]. However, fossil fuel generation often complements renewable energy, but storage and demand response can be more flexible and cost-effective[11].

This document presents the objective results in the form of graphs showing both the distribution of global research competition between these two renewable energies[12] and the impact of research on the commercial generation of solar and wave energy in the world[13].The use of solar energy to drive water treatment processes is a possible sustainable solution to the problem of global water scarcity[14]. But it is even more fruitful to use ocean water as a source of energy for the nature of its dynamics, hence the importance of studying the research trend on wave energy[15]. The following are the publications on solar and wave energy in the period 2007 - 2017. Figure 1 shows a greater number of publications related to Solar Energy, where over the years, the number of publications has increased for both energies, even more so in the case of solar energy, with double the number of articles published in 2017 compared to wave energy.

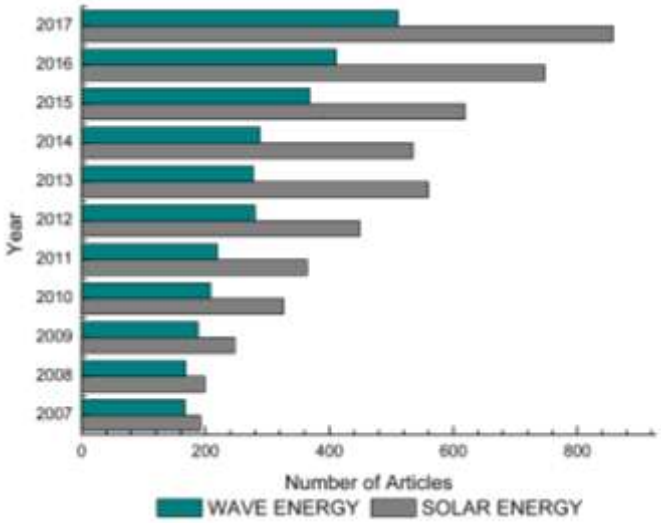


Figure 1.Number of solar energy and wave energy publications in the world, between 2007 - 2017

With the intensification of the global energy crisis and environmental pollution, the development of new energies has become the consensus of the world[16]. Among them, the ocean, which represents 70.8% of the Earth's surface, contains a wide range and considerable storage of renewable energy[17]. The energy flux density of the waves is large, which is a low-cost power source that can provide considerable power through smaller devices[18]. The rational use of marine wave power generation consumes no fuel or resources, produces no pollution, less investment and a quick return on investment[19]. Therefore, wave power generation has great potential and the exploitation of the resource depends on the knowledge and development of research[20]. However, there are some problems that need to be solved in wave power generation, problems that are currently the focus of research by many authors interested in renewable energies[21].

2. Data Sources and Methodology

The information for this research was taken online with the WOS service that has the Science Citation Index (SCIE) and the Social Science Citation Index (SSCI) database developed by Thomson Scientific. The

names of renewable energies were keywords for SCIE and SSCI to find the titles of the articles during the 2007 period. The data was stored in txt format, then analyzed in the HistCite program quantitatively and generated trend graphs of the indicators using the ORIGIN8 program.

The procedure for carrying out the bibliometric analysis was classified into three phases: the first phase consisted of the generation of data, whose information was taken from the WOS and then stored. The second phase consisted of the processing of the data, in this phase the downloaded information was taken and processed in a software. And finally, there is the third phase that was the description and report of results, all this in the period 2007-2017. All the publications obtained through the WOS database of the topic were analyzed by criteria such as year of publication, thematic categories, journals that most frequently published, countries with the highest rate of publication, total global references, geographical distribution of authors, publications with authors from the same country and with international collaboration were quantified, in addition to the publications with the greatest impact that were referenced in other publications.

3. Related Works

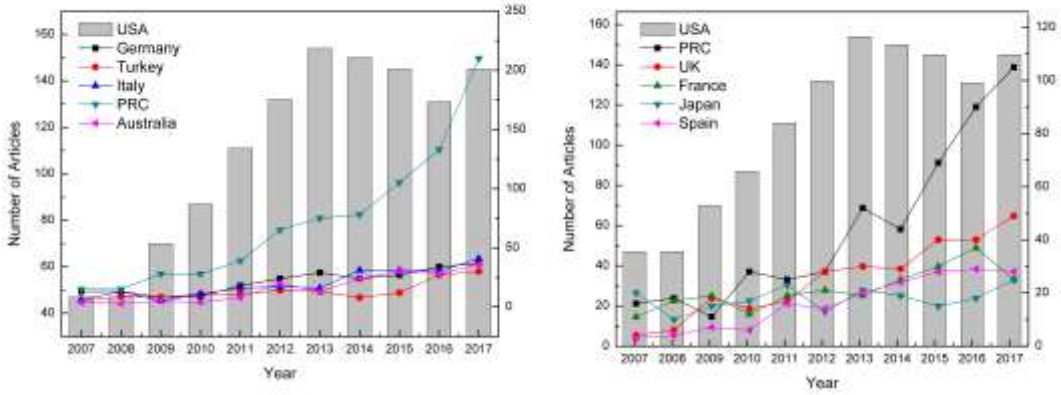
This article presents a comparative bibliometric study of two forms of renewable energy, many authors have done similar work with respect to energy forms and other related topics. A comprehensive bibliometric analysis was conducted to study the evolution of China's resource recycling policies from 1978 to 2016 and the role of major government agencies in policy formulation[22]. Similarly, a bibliometric analysis was conducted to generate graphs linking the institutions that produce publications on wind and solar energy, taking into account the international collaborations of all renewable energy magazines[23]. Likewise, the Spanish and Chinese scientific works published on the subject have been studied, using bibliometric techniques to analyze the works listed in the Web of Science in the period 2003-2012, importing the documents of which the two countries are co-authors to establish the thematic areas of interest and the institutions that participate in these investigations[24].

Finally, a bibliometric analysis based on 9514 bibliographic reports on the Web of Science from 1998 to 2017, made it possible to analyze key issues in research and development of biomass energy use, as well as the status and development trends of biomass energy use and the environment[25].

4. Results and Discussion

4.1 Characteristics of the publications

Of the 8,172 documents related to renewable energies, 62.3% refer to publications on solar energy and 37.7% to publications on wave energy in the period 2007-2017. Below is the number of publications by the United States on solar and wave energy, respectively, compared to those by the five countries with the highest research production.



(a) **(b)**

Figure 2.Top producing countries of renewable energy publications in the period 2007 - 2017, a) Solar energy, b) Wave energy

Figure 2a describes the distribution of publications on solar energy among the main research countries in the period 2007 - 2017, it can be seen that the United States is the driving force behind research on this subject; in addition, China has considerably increased its production of articles since 2009, making it the country with the highest number of publications and research level last year. Figure 2b shows the distribution of publications on wave energy among the main producing countries in the period 2007 - 2017, as with solar energy, the most productive country in terms of research is the United States, followed by China; although they differ in the countries that make up the top production and research trend at world level in this period. In 2007, the countries that preceded the United States in solar energy research produced more publications; in contrast, with wave energy, the United States was the pioneer country in research in all the years of the analysis period.

Table 1. Characteristics of the main renewable energy publications per year (2007-2017)

YEAR	TYPE	TP	NR	NR/TP
2007	Solar energy	192	11168	58,17
	Wave energy	167	3793	22,71
2008	Solar energy	199	7500	37,69
	Wave energy	168	3276	19,50
2009	Solar energy	247	8794	35,60
	Wave energy	188	3668	19,51
2010	Solar energy	326	10586	32,47
	Wave energy	208	3958	19,03
2011	Solar energy	364	14725	40,45
	Wave energy	219	3123	14,26
2012	Solar energy	449	13085	29,14
	Wave energy	280	4016	14,34
2013	Solar energy	560	11567	20,66
	Wave energy	277	3705	13,38
2014	Solar energy	535	8690	16,24
	Wave energy	288	3097	10,75
2015	Solar energy	619	7720	12,47
	Wave energy	368	2645	7,19
2016	Solar energy	748	6688	8,94
	Wave energy	411	1948	4,74
2017	Solar energy	858	2261	2,64
	Wave energy	511	827	1,62

TP: Total Production of Article, NR: Number of references, NR/TP: References cited for each Article.

Table 2. Renewable energy research organizations with the highest production (2007-2017)

TYPES	ORGANIZATIONS	TP	TLCS	TGCS
Solar Energy	Chinese Academy of Sciences, PRC	194	230	5911
	University of California, Berkeley, USA	61	120	1854
	Institute of Chemistry CAS, PRC	21	23	279
Wave Energy	Chinese Academy of Sciences, PRC	71	133	1508
	Uppsala University, Sweden	61	247	782
	Russian Academy of Sciences, Russia	58	5	390

TP: Total Production of Article, TLCS: Total Local Cited Scores, TGCS: Total Global Cited Scores.

4.2 Distribution of publications by country and research organization

The 10 countries with the highest production of publications on solar energy and wave energy are distributed on the world map as shown in figures 3 and 4, respectively; they were ranked with respect to the number of publications and the H index of the top 5 research journals in all countries. Table 2 presents the main research organizations in the world for each type of renewable energy, their publications, the country where they are located and the total citations obtained in the analysis period.

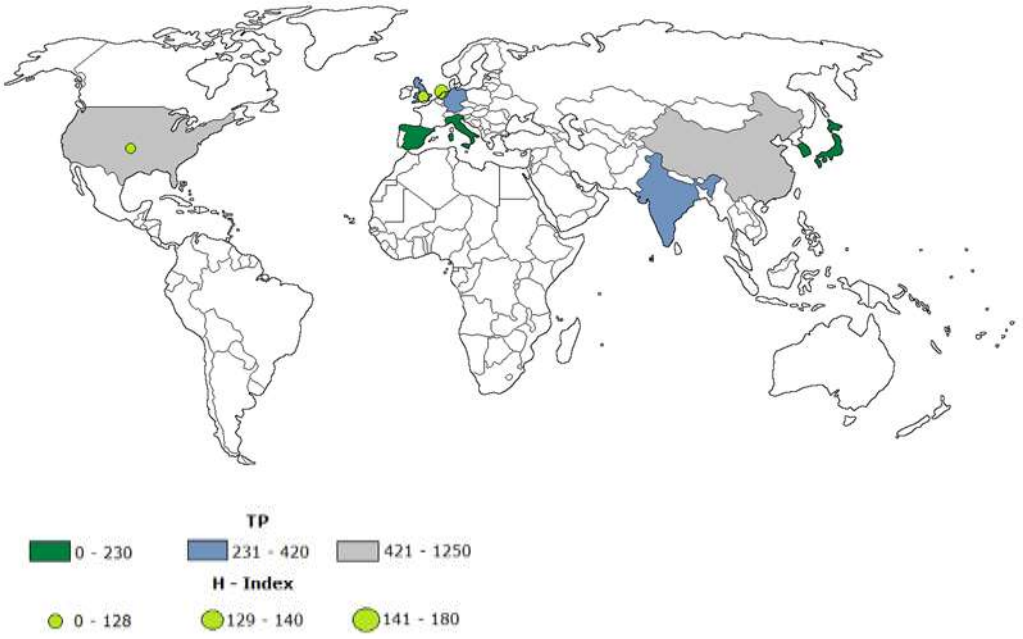


Figure 3. Distribution of the countries with the most research on solar energy and the location of the main journals with classification H – Index

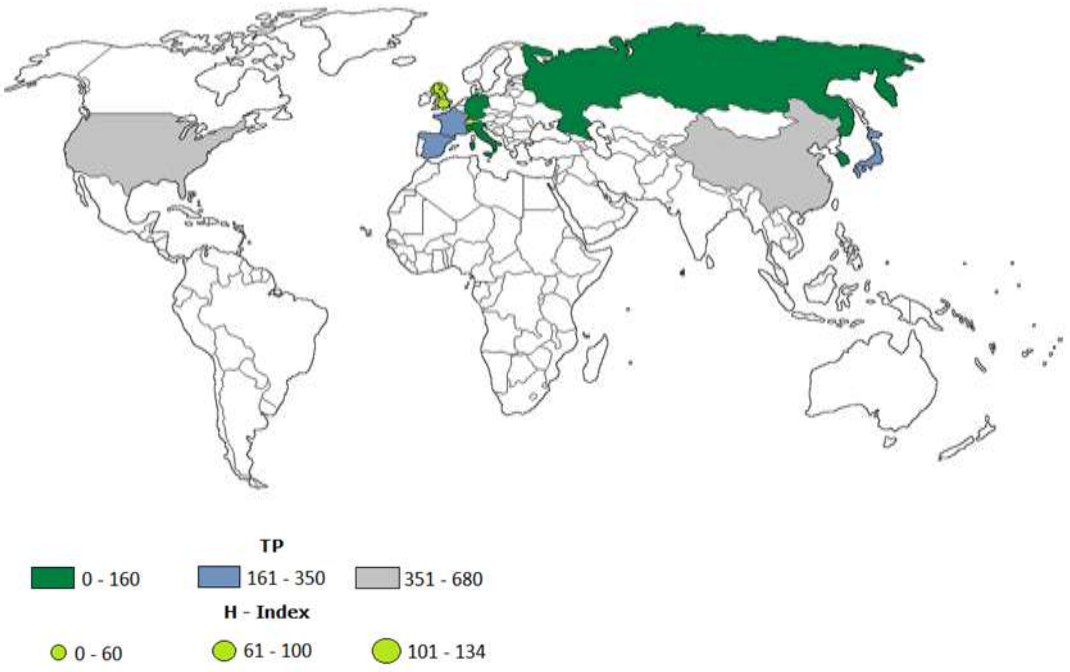
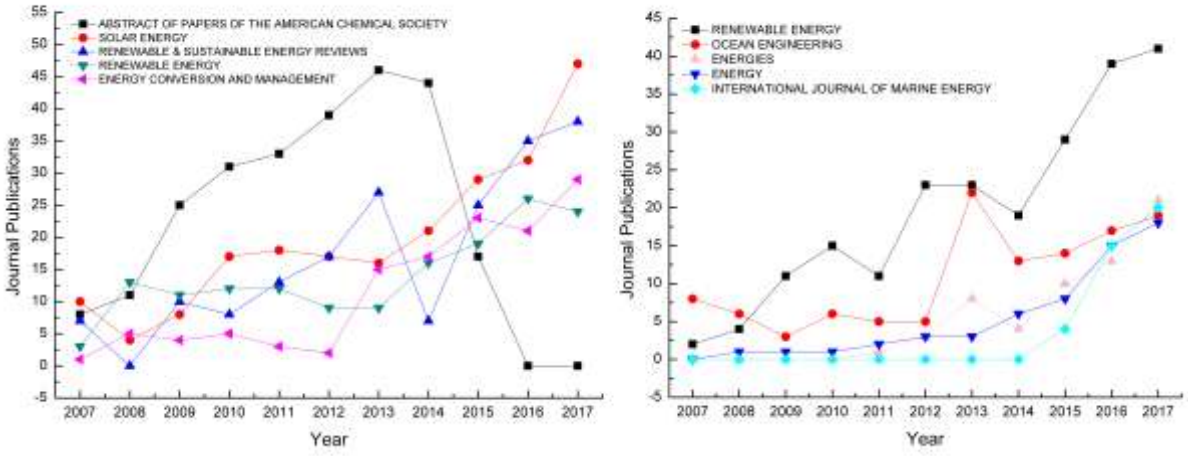


Figure 4. Distribution of the countries with the most research on wave energy and the location of the main journals with classification H – Index



(a) **(b)**

Figure 5.Publications of the 5 main journals (2007 - 2017): a) Solar energy; b) Wave energy

4.3 Thematic categories and journals

This section shows the most productive journals in the last 10 years about renewable energies under study. Below are some graphs that describe the research trend of the 5 main journals worldwide that published on solar energy and wave energy in the study period; in them you can see how the journals have performed over the years according to the number of articles published.

From figure 5, *Renewable Energy* is the one that appears in the top five of all the journals in each of the energies. This journal is located in the United Kingdom, a country that is in the top 10 in the production of articles for both renewable energies, as shown in figures 3 and 4. It is also one of the journals with the highest H - index of those studied, with 134.

4.4 Comparative analysis between the production of publications and the generation of renewable energies by country

The objective of the research is to promote new technologies that allow the technological and socio-economic growth of a country, for this reason it is of vital importance to know which countries have managed to intertwine theoretical - experimental research with the generation of clean energy that benefits the world, this allows us to visualize how effective the research is as a resource for the viability of an energy generation project, having said that a comparison is made to know the quantity of publications achieved by the countries with the greatest capacity of clean energy generation per year. This analysis will take into account the main research organizations in each renewable energy producing country. Below are the comparative graphs between the three main renewable energy generating countries under study and their research trends for the period (2007 - 2017).

Figure 6 clearly shows that the United States despite being the country with the greatest research trend worldwide, is not the country that generates the most solar energy in the world. From 2010 onwards, China increased its production of publications and coincides with a considerable investment in networks and panels for the distribution and generation of solar energy, becoming the country that produces the most solar energy per year and the second country with the highest number of publications in this area.

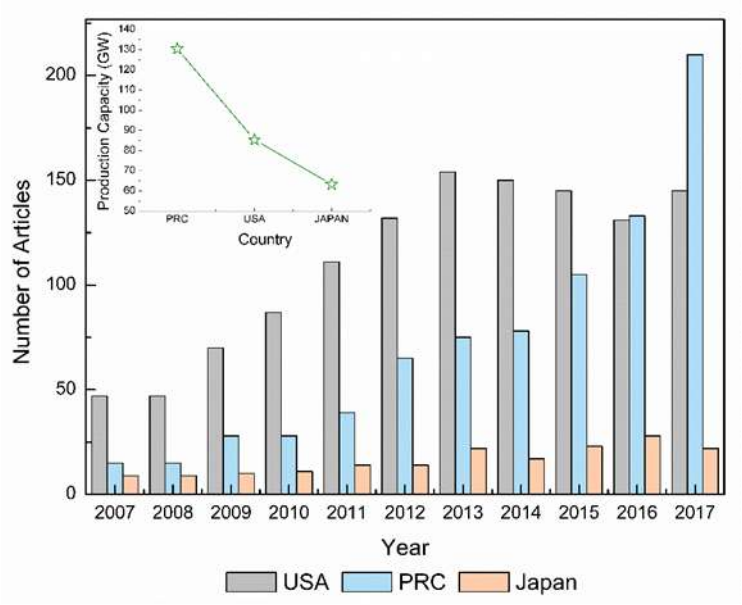


Figure 6.Number of publications in the period (2007 - 2017) from the main solar energy generating countries

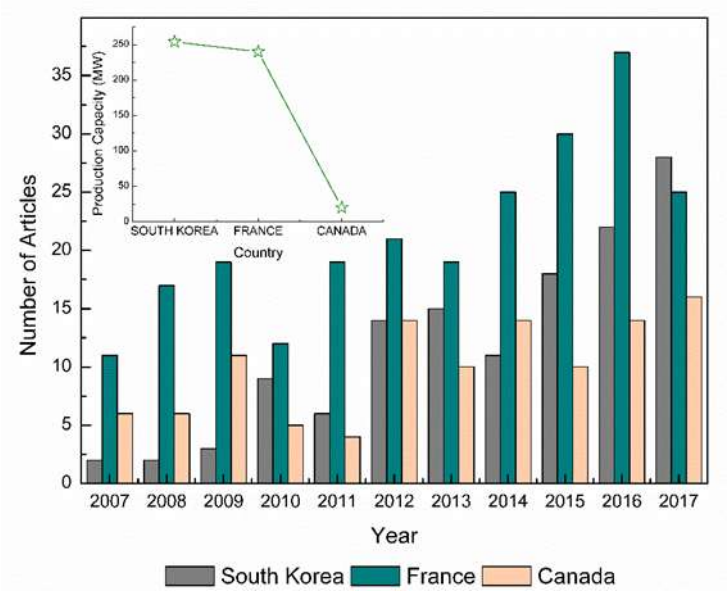


Figure 7.Number of publications in the period (2007 - 2017) from the main wave energy generating countries

Figure 7 shows that South Korea has the highest wave energy generation in the world, with a capacity that exceeds more than ten times the generating capacity of the third producer country; despite this, the country is in 10th position in the ranking of the countries with the highest production of publications in the study period, with 130 publications corresponding to only 4.2% of the data analyzed, it can be said that South Korea has been effective with the research trend applying this knowledge in the generation of energy. Currently there are many projects under development, plants that aim to exceed the capacities of the most producing countries and with investments that guarantee the use of wave energy for approximately 100 years supplying the needs of 120,000 homes, some are already finished, but are not yet commercial generation plants.

4.5 Analysis of the countries with the greatest production of publications

In this section, is represented with a map a complete analysis of the co-authorships of the countries with the largest number of publications on solar and wave energy made in VOSviewer, a very useful tool for the construction and visualization of bibliometric networks.

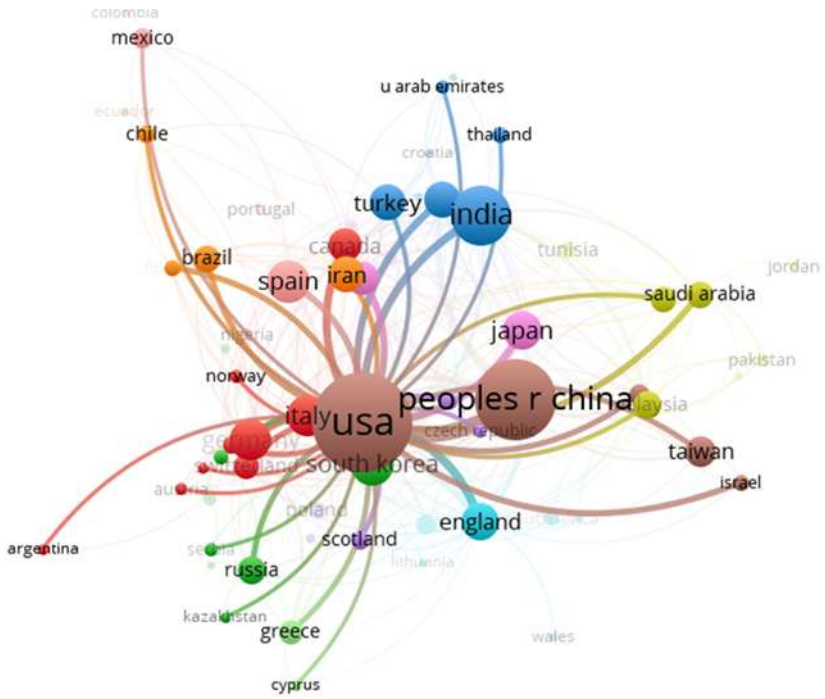


Figure 8. Map of network of co-authorships between countries producing articles on solar energy (2007 - 2017)

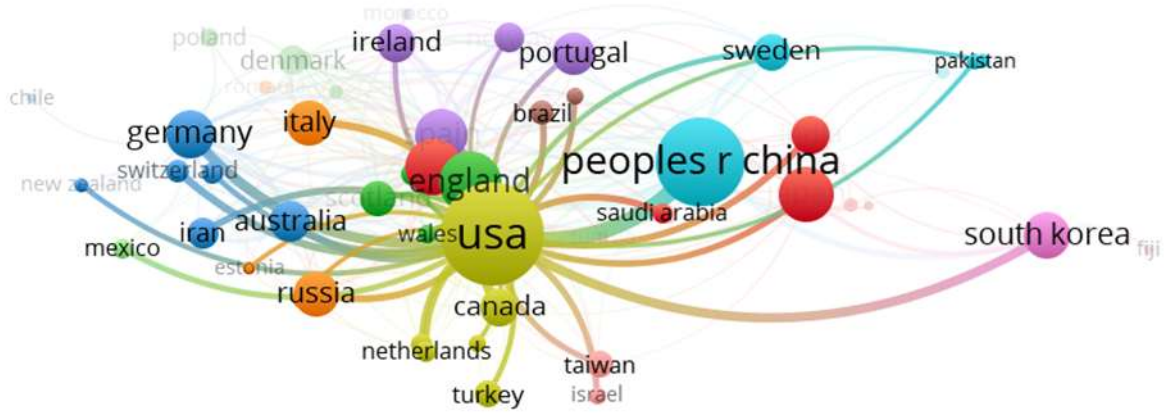


Figure 9. Map of network of co-authorships between countries producing articles on wave energy (2007 - 2017)

In both maps you can see the countries that have co-authorships with the United States, the country that produces the most publications about these renewable energies, identifying with greater size the countries with which it presents greater production.

5. Conclusions

Finally, it is concluded that research into the main renewable energy sources is growing at a sudden rate due to the environmental damage we have all suffered in recent years due to global warming; given that there is great expectation of these technologies for the solution of energy demand, environmental care and the imminent problem of the scarcity of fossil resources within a few years, countries such as the United States and China have given the first signs that the use and implementation of clean and sustainable energy sources is feasible, viable and effective.Of all the bibliometric studies done in this article, the United States and China play a very dominant role in the production of these subjects.In the last ten years, the United States contributed 23.2% and China 15.6% of the total number of publications under study, justifying these percentages, of the six research organizations studied in this article, four of them are located in these two countries, thus showing the dominance of the United States and China in the field of research on solar energy and wave energy.The countries with the highest production of these energies are the ones with the highest rate of citation of articles related to these energies, but they are not necessarily countries that produce publications, this guarantees that a country can achieve the implementation of a sustainable and renewable system without the need for high-performance research organizations, as is the case of South Korea.

Through this article, the performance of the main research institutions and/or organizations producing articles, the trend of publications and the contribution made by each country in the world were described in a graphic way.

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