DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Ochoa, Guillermo Valencia; Alvarez, Jose Nunez; Acevedo, Carlos

Article

Research evolution on renewable energies resources from 2007 to 2017 : a comparative study on solar, geothermal, wind and biomass energy

International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Ochoa, Guillermo Valencia/Alvarez, Jose Nunez et. al. (2019). Research evolution on renewable energies resources from 2007 to 2017 : a comparative study on solar, geothermal, wind and biomass energy. In: International Journal of Energy Economics and Policy 9 (6), S. 242 - 253. http://econjournals.com/index.php/ijeep/article/download/8051/4655. doi:10.32479/ijeep.8051.

This Version is available at:
http://hdl.handle.net/11159/5163

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/

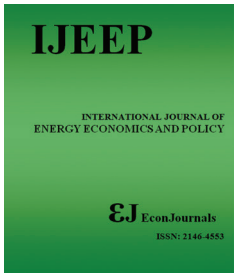
Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte. Alle auf diesem Vorblatt angegebenen Informationen einschließlich der Rechteinformationen (z.B. Nennung einer Creative Commons Lizenz) wurden automatisch generiert und müssen durch Nutzer:innen vor einer Nachnutzung sorgfältig überprüft werden. Die Lizenzangaben stammen aus Publikationsmetadaten und können Fehler oder Ungenauigkeiten enthalten.

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence. All information provided on this publication cover sheet, including copyright details (e.g. indication of a Creative Commons license), was automatically generated and must be carefully reviewed by users prior to reuse. The license information is derived from publication metadata and may contain errors or inaccuracies.

https://savearchive.zbw.eu/termsofuse

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der Leibniz-Gemeinschaft



International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2019, 9(6), 242-253.

Research Evolution on Renewable Energies Resources from 2007 to 2017: A Comparative Study on Solar, Geothermal, Wind and Biomass Energy

Guillermo Valencia Ochoa[1]*, Jose Nunez Alvarez[2], Carlos Acevedo[3]

[1]Department of Mechanical Engineer, Faculty of Engineering, Grupo de Investigación en Gestión Eficiente de la Energia-kaí, Universidad del Atlántico, Km 7 Via Puerto, 081007, Barranquilla, Atlántico, Colombia, [2]Department of Industrial Engineer, Faculty of Engineering, Grupo de Investigación en Optimización Energética GIOPEN, Universidad de la Costa, Calle 58 #55-66, 081007, Barranquilla, Atlántico, Colombia, [3]Faculty of Engineering, Universidad Francisco de Paula Santander, #0-a Avenida Gran Colombia No. 12E-96, Cúcuta, Norte de Santander, Colombia. *Email: guillermoevalencia@mail.uniatlantico.edu.co

Received: 17 April 2019 **Accepted:** 20 August 2019 **DOI:** https://doi.org/10.32479/ijeep.8051

ABSTRACT

This article presents a bibliometric analysis of trends and the research state on the main renewable energies based on information obtained from the SCIE/SSCI database for the period 2007-2017. The analysis is aimed at solar energy, geothermal energy, wind energy and biomass energy source. The results generated from the bibliometric techniques used allowed to obtain the behavior of the publications production and the influence that different countries and universities have on this subject. From the 10,363 publications, the 87.5% are journal articles and the 98% are in English language. In addition, 49.03% of the publications corresponded to solar energy, 33.83% to wind energy, 12.77% to biomass and 4.37% to geothermal energy. In the 10 years analyzed, the United States has been the most influential country in this research area, presenting the largest volume of publications in each of the renewable energies source studied. The results of this paper provide to energy researchers a relevant overview of the tendencies and scope of the main renewable energies worldwide. In addition, to support scientific decision and prospective investment in research center, relevant data are presented on the countries producing these renewable energies and their relationship with the production of publications.

Keywords: Bibliometric Research, Renewable Energies, Solar Energy, Wind Energy, Geothermal Energy, Biomass Energy
JEL Classification: Q42

1. INTRODUCTION

The energy demand has reached very high levels last decade, the main reason for this phenomena is the rapid increase in urbanization, neighborhoods, built environment, public transport and services (York and Bell, 2019; Miller and Rupp, 2018; Benedek et al., 2018). The combustion of fossil fuels is largely responsible for the problems of climate change, air pollution and energy insecurity (Hanh and Kakinaka, 2019; Zerrahn et al., 2018). A combination of wind, water and solar energy is the best alternative to fossil fuels (Lewis, 2007), (ASTM G-173-03, 2002), because renewable sources of energy have almost zero emissions of greenhouse gases and other air pollutants (Kim et al., 2018), (Chen et al., 2019), no long-term waste disposal problems and no risk of catastrophic accidents (Delucchi and Jacobson, 2013; Bulut and Gonul, 2018; Harjanne and Korhonen, 2019; Zeng et al., 2019). Environmental and social problems related to energy use have motivated the development of sustainable energy technologies (Baruah and Enweremadu, 2019; Moorthy et al., 2019; Washburn and Romero, 2019), such as wind turbines, carbon capture and storage, and hydrogen vehicles. Public acceptance of these technologies is crucial to their successful introduction

This Journal is licensed under a Creative Commons Attribution 4.0 International License

into society (Afonso et al., 2017; Sakellariou, 2017; Schumacher et al., 2019; Haufe and Ehrhart, 2018). It is complex to achieve full acceptance because of the fear of change that exists in society, but sooner or later everything becomes necessary (Hentschel et al., 2018; Burcu and Ozturk, 2019; Hansen et al., 2019).

The development of renewable energies is a necessary step towards mitigating climate change (Zhou et al., 2018; Yuan et al., 2018; Lin and Zhu, 2019), which is why these issues have often been linked (Hamilton et al., 2018), abundant, cheap and clean renewable energy sources (Navratil et al., 2019),(Assali et al., 2019) are a promising alternative for promoting modern processes (Umar, 2017; Lin and Chen et al., 2019; Canaria et al., 2018), these promise to be the future of the whole world because they are sources that nature provides ceaselessly (Draycott, 2019); while renewable energy technologies (RET) (Narayanan et al., 2019; Selosse et al., 2018; Jacobson et al., 2017) increase their participation in power generation systems around the world, some questions remain unanswered, about the projects of these technologies (Shin-Li, 2019).

The attitude that society takes (Reboredo and Ugolini, 2018) challenges is influenced by the perceived costs of the RET (Kreuz and Felix, 2018; Olson-hazboun et al., 2018; "The difference between popularity and prestige in the sciences and in the social sciences: A bibliometric analysis" by Franceschet, 2010; Zhang et al., 2018), the risks and rewards, the positive and negative feelings in response to the technology given the long planning period and the large sums of capital required by RET and, in some cases, the fact that it is subsidized, it is desirable for decision-makers to recognize public opinion (Hache, 2018; Overland, 2019; Bayulgen and Benegal, 2019) and at least perceive if opinions are based on biased perceptions (Ribeiro et al., 2018), (Sweerts et al., 2019). A clear example of what needs to be done by decision-makers is the case of the implementation of renewable energies in Brazil (Bradshaw, 2017), a great example for other Latin American countries to follow (Arias-gaviria et al., 2019; Pietrosemoli and Rodríguez-monroy, 2019; Ylipulli et al., 2014); this case is analyzed by some authors within a very interesting study, where the political and institutional context led to regulatory reforms in the electricity sector since the nineties (Djørup et al., 2018).

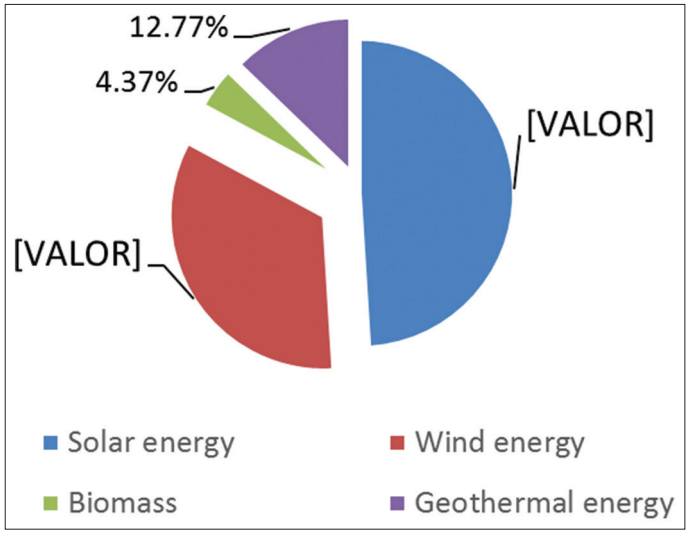
It was demonstrated that pre-existing hydropower infrastructure, both physical and institutional, has created significant limitations in the adoption of alternative forms of energy (Braungardt et al., 2019), (Fadly and Fontes, 2019). In this context, the factors that have allowed the participation of wind energy were examined (Hernández-Escobedo et al., 2018) and solar (Koenig, 1970) in the Brazilian energy supply (Bradshaw, 2017). In addition, the national government have undertaken innovative changes to encourage the use of renewable energy last decade (Bistline et al., 2019). While each country demographically has its limitations with respect to clean energy sources, it is possible to think of a future solution, even if this project takes many years.

The worldwide relevance of the different RET has been widely demonstrated, solar energy (Denholm and Margolis, 2007), wind energy, biomass and geothermal energy (Clauser and Markus, 2018), and the perception of the viability of its implementation despite the initial costs involved (Scaramuzzino et al., 2019), this perception varies according to the socioeconomic situation of each country and technological development (Eren et al., 2019). Figure 1 shows the percentage distribution of publications of the renewable energy research from 2007 to 2017.

The renewable energy with the most amount of research publication is the solar energy with approximately half of the publications during this period considered (Sarmeinto et al., 2017), converting this energy resource into the optimal, effective and efficient renewable energy to be implemented by most countries around the world in the short term future (Urban et al.,), (Liu et al., 2019) (Navratila et al., 2019).

Solar energy is the one with the greatest research impact (Mekhilef et al., 2011), perhaps by its nature and tentative efficiency (Dubey et al., 2013), because it is the conversion of sunlight energy into electricity (Arapkoules et al., 2015), either directly using photovoltaic energy (Mascarós, 2016), indirectly by using concentrated solar energy, or a combination of both (Denholm and Margolis, 2007), (Cepeda and Sierra, 2016). Currently, solar energy conversion is widely used to generate heat and produce electricity (Eitan and Herman, 2019). A comparative study on global energy consumption published by the International Energy Agency shows that solar panel installations will supply about 45% of the world's energy demand in 2050 (Pina et al., 2014), (Amri, 2019), and solar thermal energy is gaining popularity in industrial applications (Mekhilef et al., 2011). Nevertheless, solar energy conversion technologies face costs and scalability obstacles in the technologies required for a complete energy system, because of to provide a truly extended primary energy source, solar energy must be captured, converted and stored cost-effectively (Trainer, 2017; Keck et al., 2019; Obeng-darko, 2019; Azhgaliyeva, 2019). New developments in nanotechnology, biotechnology, materials and physical sciences may allow approaches of gradual change of cost-effective systems (Kartite and Cherkaoui, 2019), and scalable on a global scale for the use of solar energy. China (PRC) is the world's largest market for photovoltaics and solar thermal, but

Figure 1: Distribution of the worldwide renewable energy publications from 2007 to 2017



solar energy production accounted for only 1% of China's total energy demand in 2017 (Liu, 2019), (Hou et al., 2018), and the 66% of demand still comes from coal, something the country's National Energy Administration wants to change drastically by 2050, partly because of China's known air pollution problems (Chen et al., 2019), but a very different energy mix could be propelling China in 2050 (Camargo-Ramirez et al., 2018), (Nguyen et al., 2019).

It is expected that renewable energies could supply 86% of the country's energy needs, and solar energy would provide about a third of that (Urban et al., 2018). Among renewable energies, wind energy (Keček et al., 2019) is one of the most sustainable, playing an important role for the development of some countries such as Mexico (Hernández-Escobedo et al., 2018). In Latin America there is a growth in the implementation of renewable energy, with an installed capacity of more than 168.7 GW in 2016, China is the main producer of wind energy in the world (Zhou et al., 2016), (Hu et al., 2018). The country is making massive investments in the renewable energy sector (Ding et al., 2019), with a focus on wind energy. According to the World Wind Energy Association, the Chinese wind energy market is the largest in the world, with a global market share of 52% and a project to install 10 GW of offshore wind before the end of 2020 (Jacobson et al., 2017).

On the other hand, Biomass is a renewable and clean source of energy, at levels equal to and sometimes higher than coal (Iqbal et al., 2018), (Helmisaari et al., 2002); Ozturk and Bilgili (2015); Mambura et al. conducted studies in South Africa and claim that the benefit of biomass is that it could coexist with coal, thus reducing greenhouse gases and global warming (Mamvura et al., 2018) (Svoboda et al., 1199). The use of forest biomass for energy production requires careful attention to sustainable silvicultural practices (Frombo et al., 2016), which is a complex task because of the different environmental and economic issues that need to be considered. Finland is the country that concentrates the largest plants of this type in the world occupying 65% of the market, the concrete generation of all its plants totals around 970 MW. Finnish production benefits from resources such as wood, cardboard, plastic, agricultural waste and paper as energy; this benefits thousands of households every year (Helmisaari et al., 2002).

In addition, there is geothermal energy produced from natural steam or permeable hot water reservoirs (Umar, 2017), many countries welcome this type of energy, so much so that in January 2017 the Chinese government launched the first special plan for the development of geothermal energy called the "13th 5-year plan for the development and use of geothermal energy (2016-2020)," which promotes the development of geothermal energy at the national strategic energy level (Hou et al., 2018). The United States has an installed capacity of 3,591 MW, making it the country with the highest geothermal energy productivity (Koenig, 1970). Geothermal energy is among the cheapest forms of renewable electricity. However, in the years to come, geothermal electricity may be restricted to a limited number of regions around the world that have these particularly favorable fields. This would exclude most of the earth's continental land mass, which is hot but lacks natural steam or hot water reservoirs. In addition, it is constrained by wind and solar power generation; this can become a serious competitive disadvantage, as primary fossil energies are being replaced (Clauser and Markus, 2018).

While bibliometric review of scientific topics is widely used in some field of study, chronological evolution of concepts and scientific collaboration between countries related to RET studies have not been exhaustively investigated. To complete this gap, some bibliometric indicators of the articles published are presented to evaluate and quantify the evolution of the research publication related to the mains renewable energies resources, solar, geothermal, wind and biomass energy from 2007 to 2017 to identify the topical subjects, extent of international collaboration and scientific productivity of the countries to which the authors declared they were associated when publishing the journals.

2. METHODOLOGY

A bibliometric analysis is able to show patterns of research publications from a database present in the literature. This analysis exploits the relationships between citations in academic journals and shows a clear view of a specific topic, where the importance of an issue can be highlighted within a range of years. In additions, this analysis can be used to analyze the relationship that articles have in different fields.

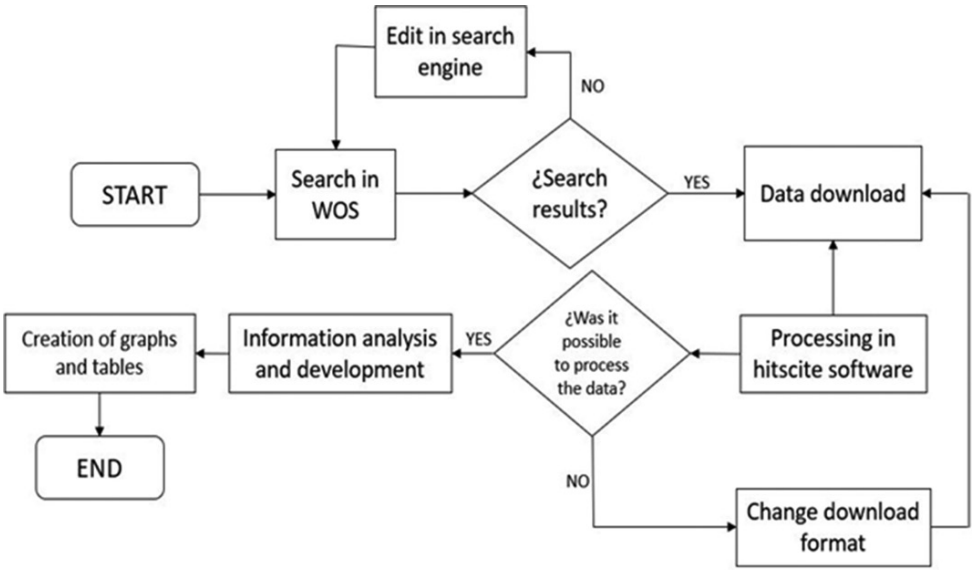
2.1. Objective of the Study

The primary objective of this study focuses on the analysis of the different bibliometric indicators related to the investigation of RET with the articles obtained in Web of Science, and processed in HistCite. In this study, the information search equation allows to select the information avoidable in the database to be analyzed by some categories such as countries, journals, authors, institutions and indicators of citation scores.

2.2. Analysis Procedure

For the analysis of the information obtained and the generation of the results, it was necessary to follow the steps shown in Figure 2. The flowchart shows the five steps of the bibliometric study from the journal related to RET. In the first stage, the search of a subject is defined. This search is determined by the keywords that facilitate to obtain the information to be analyzed. The general theme of this article is the renewable energies resources, so the appropriate keywords where "solar energy," "geothermal energy," "wind energy" and "biomass energy." In the second stage, the previous keywords were used to search the articles for the bibliometric analysis. For this procedure, web of science was used to obtain the information of the journal. In the third stage, the tool HistCite is used to calculate the bibliometric indicators from the metasearch of the journal. In the fourth stage, the results analysis is obtained with the HitsCite tool to present solid and consistent information about the evolution and tendency of this field of study. The final stage, graphs and tables were elaborated to make the discussion presented in this paper. The information for this research was taken online with the WOS service which has the science citation index (SCIE) and the Social science citation index (SSCI) database developed by Thomson scientific.

Figure 2: Procedure for bibliometric analysis



The names of the main renewable energies were used as search phrases to search for SCIE and SSCI titles, abstracts and keywords from 2007 to 2017 to obtain the 10,363 publications studied in this research. The 49.08% from the publications corresponded to solar energy, 33.79% to wind energy, 12.76% to biomass and 4.37% to geothermal energy, all contained author names, titles, abstracts, publication dates, document types, addresses and citations. The data were stored in txt format, to be analyzed quantitatively in the HistCite program to generate trend graphs of the indicators to measure the quality, impact of countries and journals in this field of research.

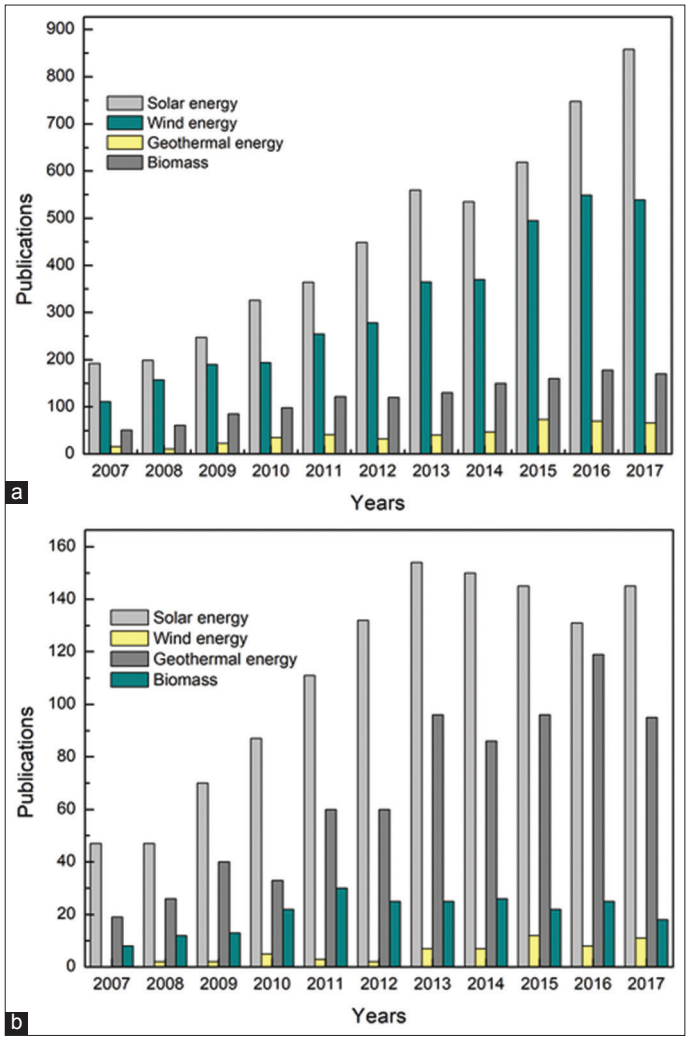
3. RESULTS AND DISCUSSION

3.1. Characteristics of the Publications

The 10,363 documents related to the main renewable energies SCIE and SSCI from 2007 to 2017, were classified in 4 subdivisions, each corresponding to a type of renewable energy. The solar energy publications achieve the 48.99% from the global production, with 5077 documents, where the 76.9% were journal articles, 7.5% review proceeding and 3.4% were editorial material. The worldwide evolution on renewable energy resource is shown in Figure 3a, where the trend is growing for all the energy type but is largest for the solar energy, follow by the wind energy publications. This result can be explained because the solar energy has become the sector where the capacity to produce electricity has increased the most worldwide and that the increase in its investments grows more than the rest of renewable energy sources, and even those of fossil fuels.

The growth of research publication over the 10 years studied related to United States is presented in Figure 3b, where all the renewable energies have become an important alternative in the energy transition period. It is expected that the United States will remain in the position with more publications related to renewable energy, as the deployment of solar and wind energy facilities and research in the country continues to increase in markets and educational institutions, regardless of the low oil and gas prices they may have at some time. Growth could be much greater if the costs of RET fall due to economic, social and environmental factors that favor renewable energy and make it competitive with conventional energy sources.

Figure 3: Renewable energy resource publications from 2007 to 2017, (a) worldwide, (b) United states of America



The number of U.S. publications on solar energy, geothermal energy, wind energy and biomass, respectively, compared to other countries within the top of production and research is presented in Figure 4. Figure 4a shows that countries such as Germany and China produced more publications during 2007 and 2008. After this, the United States increased its production from 2009 until it became the country with the greatest research contribution on solar energy in the world, this phenomenon is due to the effect of the inclusion of renewable energies in the US Energy Policy laws during the years prior to 2009, which focused on the conservation of natural resources, the development of these energy sources in different economic sectors, through concessions and fiscal incentives for both renewable and non-renewable energy sources.

Energy efficiency programs were implemented to achieve a rational use and preservation of the environment. On the other hand, the administration of Barack Obama proposed an important reform of the country's energy policy, declaring the need to reduce CO_2 emissions through a national emission program, which also resulted in helping to increase the implementation and study of other renewable and sustainable energy in this country. Figure 4b shows the superiority of Turkey in terms of research over a couple of years but then decreased to the point of producing between 2010 and 2013 less than half of the publications made in 2009. In addition, countries such as Australia, China and the United States were in growth, the latter being the country with the largest production of articles on Geothermal Energy during this period. The geothermal energy evolution is a consequence of nature of this source, due to is a clean, geographically diverse and carbon-free energy where the earth's heat is harnessed to generate naturally renewable electricity.

Wind energy has become an important energy resource in many countries and is recognised as a safe and affordable source of energy. The Figure 4c shows a big difference in the production of publications on Wind Energy in the United States with the rest of the countries, except with China. As the United States is in continuous research progress to the point of generating more articles during the past year 2017.

The result is a consequence on the installation capacity increase, where nearly 55 GW of wind power was added during 2016 around the word, representing a total global increase of 12 %, reaching 487 GW in the cumulative world total below 22 % reached in 2015. By the end of 2016, more than 90 countries had some commercial activity in wind power and 29 countries in all regions have come to have more than 1 GW installed and in operation. Wind energy is the source of energy that runs first in terms of new installed capacity in Europe and the United States, and second in China. In 2016, China ranked first in terms of new wind farms far removed from the United States, Germany and India. Spain, the United Kingdom, France, Canada, Brazil and Italy are also among the top ten countries. China installed almost half of what was installed in the world. New markets have appeared in different regions of Asia, Africa, Latin America and the Middle East. At the end of 2016 the leading countries in terms of installed capacity per inhabitant were Denmark, Sweden, Germany, Ireland and Spain.

Figure 4: Annual energies publications in the United States and other producing countries during the same period (2007-2017) (a) solar energy; (b) geothermal energy; (c) wind energy; (d) biomass

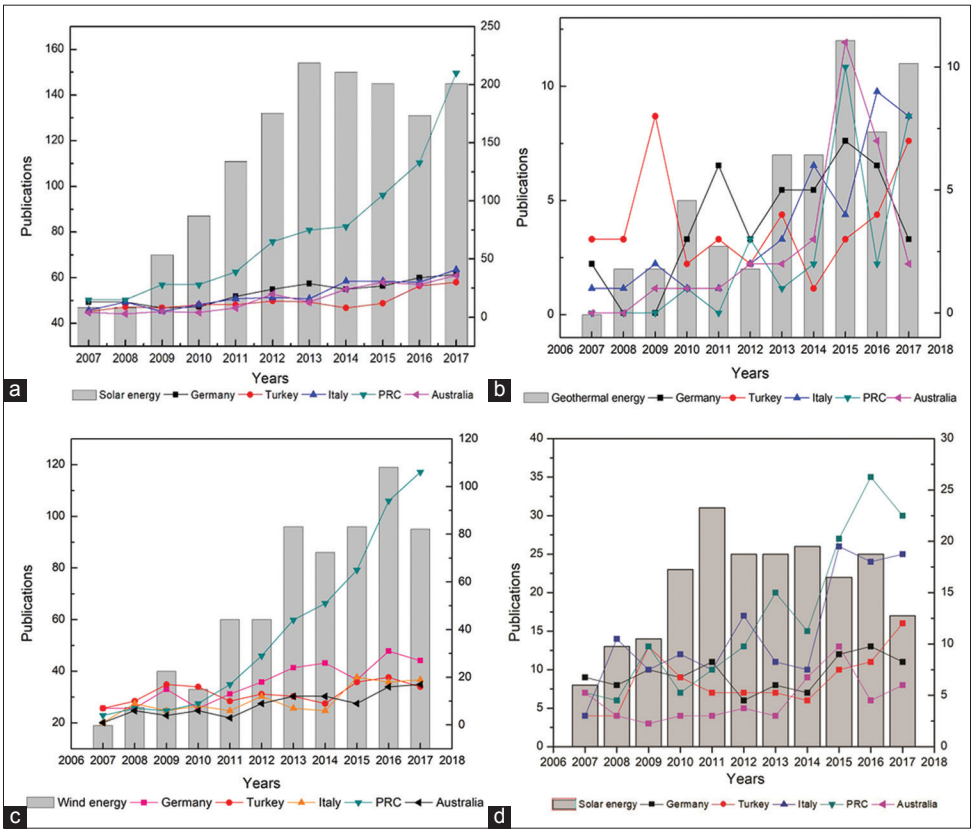


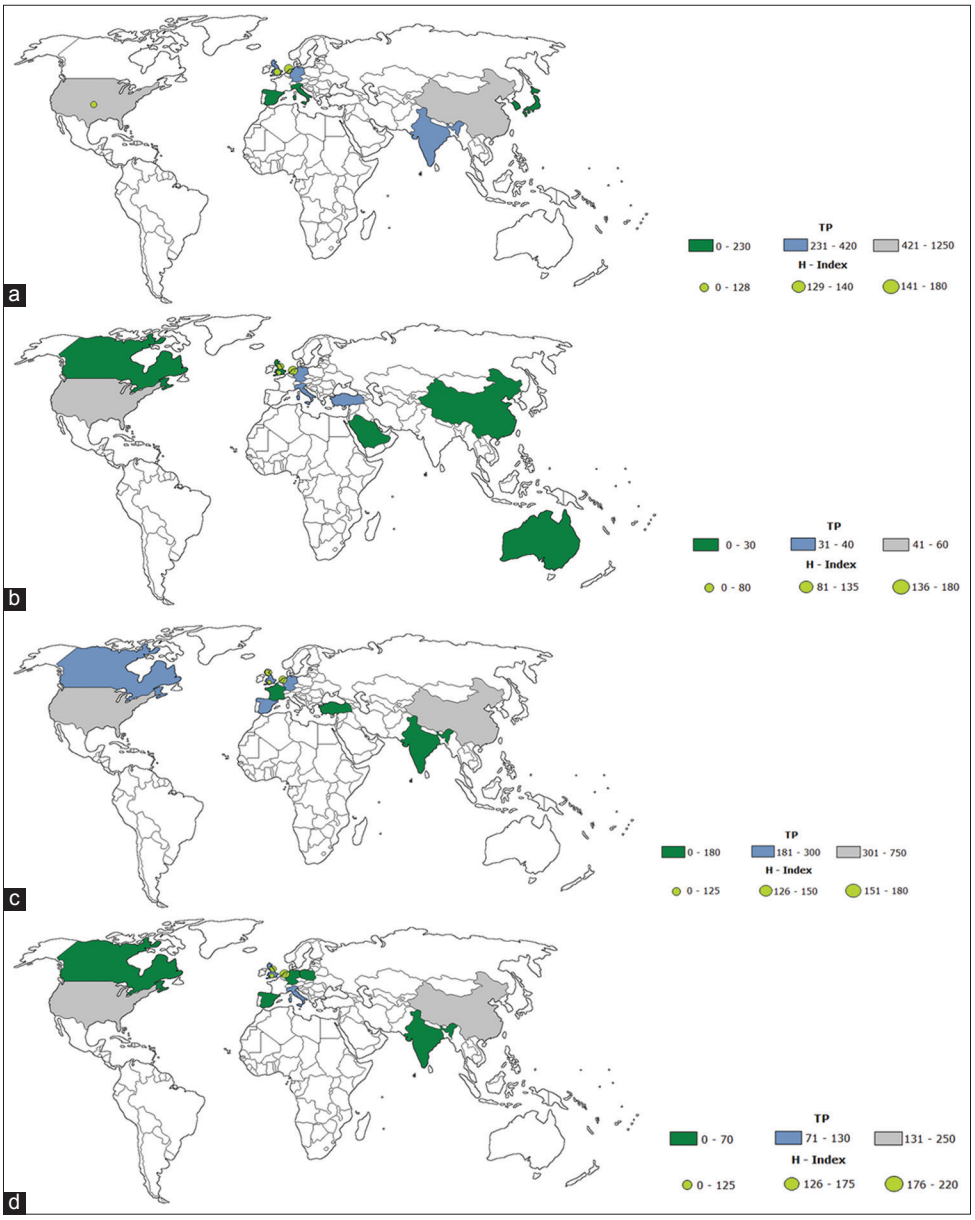
Figure 4d shows that the United States was totally dominant from 2007 to 2014 in publications on Biomass as an energy resource, but its production decreased. In addition to this, countries such as China and Italy considerably increased their production, surpassing the United States in the last 2 years, these results are due to the fact that Italy has shown the viability of using biomass as a resource for the direct production of electrical energy by means of combustion and gasification processes, since it has a level of agricultural production capable of satisfying a large part of the energy demand of this country.

3.2. Distribution of Publications by Country and Research Organization

The 10 most productive countries of the main renewable energies can be seen in Figure 5, they were classified with respect to the number of publications and the H index of the 5 main research journals in all the countries. These results are due to the energy transition that has taken place in these countries, where it is expected to derive a high level of penetration in energy systems in the next decade, reaching values such as Denmark and the region of Texas in the United States, which already reached a penetration level of 50%. The high market penetration of these renewable sources and solar and wind energy, will allow an improvement in the quantity and quality of publications in these countries. However, it is necessary to overcome the challenges of fluctuation that these resources present for their easy integration into the electricity generation network. The improvement in the quality and quantity of publications is related to the interest in reaching 100% penetration of these renewable energy sources.

The results show that the different renewable energy sources studied in this research are already a reality in many countries and

Figure 5: The 10 most producing countries (2007-2017) with the number of publications and index H: (a) solar energy; (b) geothermal energy; (c) wind energy and (d) biomass



research institutes around the world as shown in Table 1, where the total global citation score (TGCS) and total local citation score is presented for each organization according the energy source. The relevant position of the Chinese Academy of Sciences located in China (TGCS=5911) is because it is the largest research organization in the world, with a total production of 194 publication related to this topic with a high quality that allow to be cited by others researcher.

3.3. Comparative Analysis between the Publication and the Production of Renewable Energies by Country

This analysis considers the main research organizations in each country producing renewable energy, with this seeks to analyze how much research impact the energy production, which is final propose desired throughout the world, that renewable energy uses do not remain on paper or in a feasibility study but becomes a reality for all countries. Figure 6 shows a comparative analysis between the 3 main countries producing solar, geothermal, wind and biomass energy, respectively, and the research trend from 2007 to 2017. There is a fairly good correspondence between the solar energy produced and the publication evolution as shown in Figure 6a, PRC has also the highest solar energy production (160 GW), more than 200 publication in 2017, which mean an important impact of the academic activity on the number of solar applications in this country. On the other hand, Japan is the country with the lower number of publications, reaching only a solar production of 65 GW. These results can be explained because of this type of energy resource is considered as an

Figure 6: Publications behavior between the 3 main countries from 2007 to 2017 related to: (a) solar energy; (b) geothermal energy; (c) wind energy and (d) biomass energy

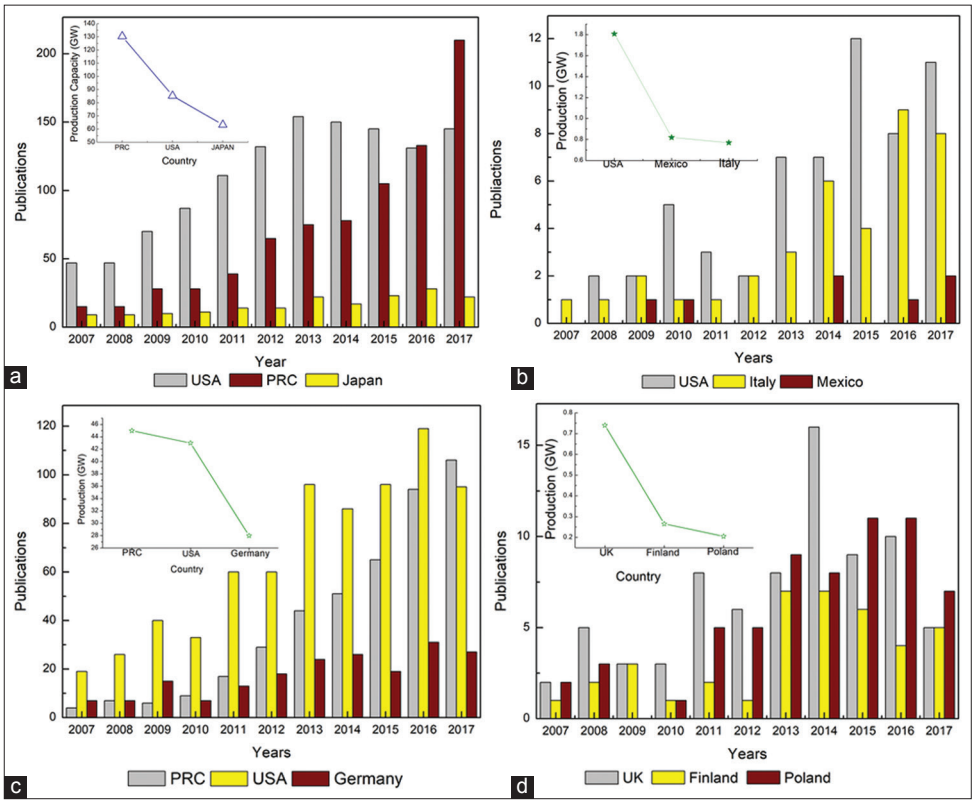


Table 1: The 3 research organizations of the main renewable energies with the highest production (2007-2017)

Energy	Organizations	TP	Total global citation score	Total local citation score
Solar energy	Chinese academy of sciences, China	194	5911	230
	University of California, Berkeley, USA	61	1854	120
	Institute of chemistry CAS, China	21	279	23
Geothermal energy	Helmholtz association, Germany	23	45	6
	University of Ontario institute technology, Canada	13	93	15
	ETH Zurich, Switzerland	12	238	29
Wind energy	Technical University of Denmark, Denmark	67	886	72
	Chinese academy of sciences, China	66	1333	128
	Indian institute of technology, India	64	340	57
Biomass	United States Department of Energy, USA	31	500	23
	United States Department of Agriculture USA	28	374	14
	Chinese Academy of Sciences, China	25	412	15

emerging technology where the knowledge and research result play a relevant role on the product available in the market.

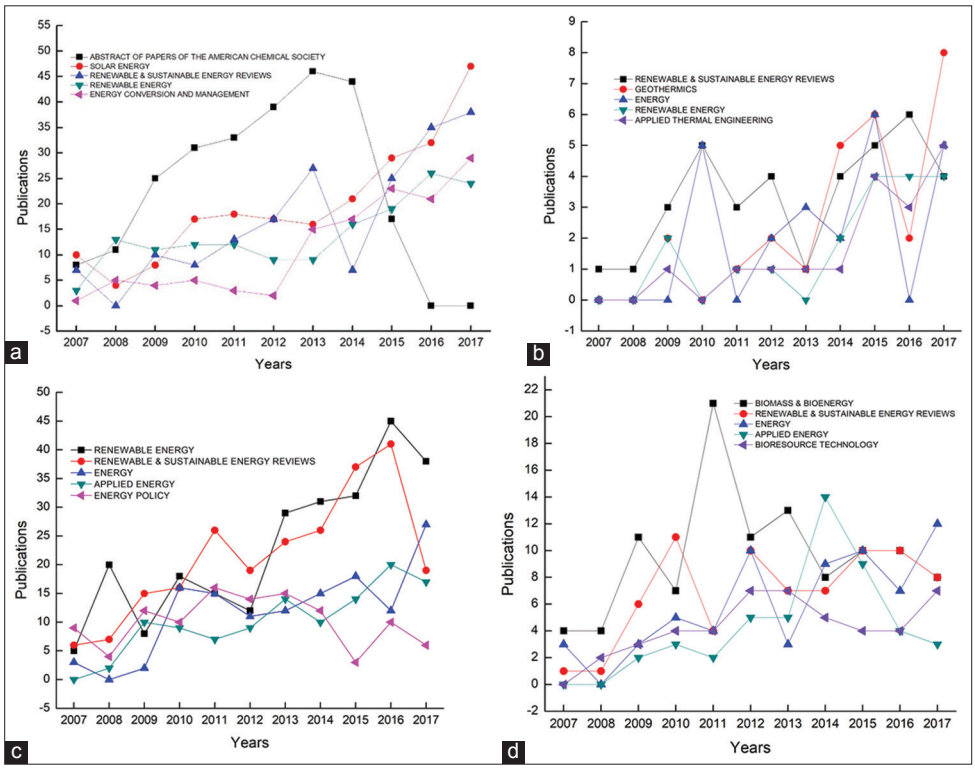
A similar case occurs with wind energy as shown in Figure 6c, where the country with the highest scientific production recently corresponds to the country with the highest wind energy production, which is due to the important developments of PRC and USA manufacturers in advancing wind turbine technology to a high degree of maturity, where they can operate as a highly reliable machine, virtually without the need for permanent attention and an interface with a complex electrical grid that must supply high quality electricity. The results show that the rate at which the volume of publications on wind energy increases is dizzying. Additionally, these developments have allowed an increase in the height at which wind turbines currently operate and the average power per unit is currently around 2 MW for manufacturers in the three countries considered. The high levels of power generated in these three countries is due to the fact that this technology currently in use has evolved from the 25-40 kW turbines in the 1980s to the current 8 MW turbines. The predominant nominal power of turbines being installed onshore is in the range of 2-4 MW, while those installed in offshore wind farms are in the range of 3-8 MW.

3.4. Thematic Categories and Journals

To identify the journals where the research results are concentrated for each type of renewable energy source, an evolution of the number of papers published was studied for the top 5 journals, as shown in Figure 7. The journals considered have a publication Scopus index Q1 and Q2, that demonstrate the importance and quality of the research that has been developed on this subject and the positive impact of these in the industry. In the area of solar energy, the journals "solar energy" and "renewable sustainable energy reviews," have increased the number of publications, duplicating in the last 4 years as shown in Figure 7a. It is expected that the volume of publications in these journals will continue to increase in the coming years thanks to investments in research centers, training of human capital specialized in the area, tax incentives that are being granted in different countries for the use of these energies and the diversification of the energy matrix in many countries where solar and wind energy have an important contribution. In the other energy source, in addition to the journal "renewable sustainable energy reviews," other journals are relevance such as "Geothermics" in Figure 7b, "renewable energy" in Figure 7c and "biomass bioenergy" in Figure 7d. These results show a clear tendency of the researchers to publish the works in the most specialized journal of the area, where the topics are more related to the fundamentals and the application of the energy conversion phenomenon.

The journal with the highest impact factor related to the types of renewable energy studied is the journal "renewable and sustainable energy reviews" with 193 in the h index, leading the number of articles published in several years for the different areas. In this journal is published about 22% of the documents reported in solar energy, which confirm the relevance of this journal. In addition, about 43% of the publications in solar energy and 48% in wind energy are distributed in the top 5 journals reported in this study. These results serve as a guide to focus the search for research results of high quality and impact in the areas of renewable energy, in addition to being referring to the time of selecting the magazine to publish.

Figure 7: Publications of the 5 main journals from 2007 to 2017 related to: (a) solar energy; (b) geothermal energy; (c) wind energy and (d) biomass energy



3.5. Analysis of Correlations between Thematic Axes using Network Maps

In this section, the correlations between the three main renewable energies is studied. There is a close relationship between producer countries and research organizations. For this analysis was used a set of data extracted from the WOS corresponding to the first thousand articles of solar energy, wind and biomass in the period of study. The software used is VOS viewer tool, that allows to determine the construction and visualization of bibliometric networks. The selected articles for this study are the most cited according to the bibliometric analysis. Figure 8 shows the co-authorships in articles on the three main RET, where a powerful relation between Stolarski, from University of Warmia and Mazury in Olsztyn, and Stefan Szczukowski had published together some paper related to biomass source in the biomass and bioenergy journal and the renewable and sustainable energy reviews.

Collaborative network in the RET research field is shown in Figure 9. The number of networked articles between institutions is 34% higher than the number of articles published individually by each institution in each country. This network was built from the 30 most academically productive countries in renewable energy from 2007 to 2017.

The largest number of co-authors was between the Chinese Academic Science and Univ Chinese Acad Sci, with a combined number of 12 publications. The United States continues to maintain its importance from the different perspectives analyzed in the advancement of RET research through collaborative work, on the other hand the progress and increasing coverage in this area by the institutions of South Korea and Japan. These results are due to the fact that it is the Asian countries that are leading the worldwide growth of installed electricity generation capacity from renewable energies, with growth projections of up to 70% by 2030. Networking in Asian countries is also a consequence of concern over population growth, the need to improve the living conditions of its inhabitants and the ever-increasing economic activity, factors that imply an increasing in the energy demand.

The countries shown in Figure 10, with a network of co-authors of articles related to RET, correspond to the main countries manufacturers of these technologies. In the case of wind energy source, GE from the United States, Siemens from Germany and Goldwind stand out. Gamesa, Siemens Sinovel, Enercon and Suzlon also stand out. Other manufacturers that have appeared in the ranking of the first ten of these years have been Nordex (Germany), Repower (Germany), and the Chinese Donghang, Guodian, Ming Yang, Senvion, Envision and CSIC that appeared in 2015. These results confirm the close relationship between these countries to lead and advance in the development of RET.

Figure 8: Co-authorships in articles on the three mains RET

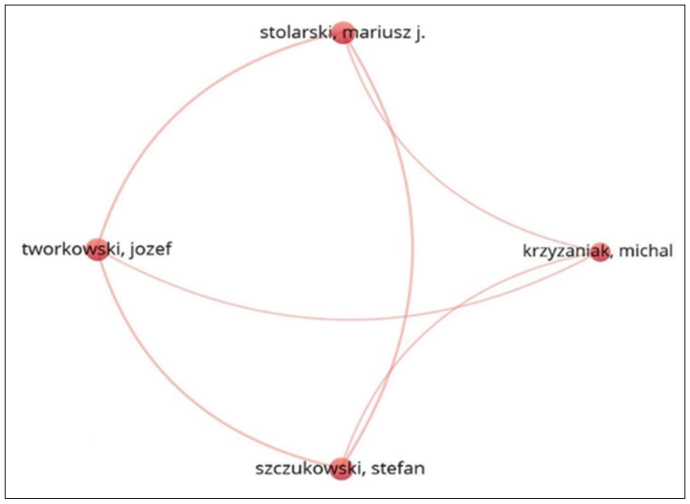


Figure 9: Co-authorships in the research organizations of the three mains RET

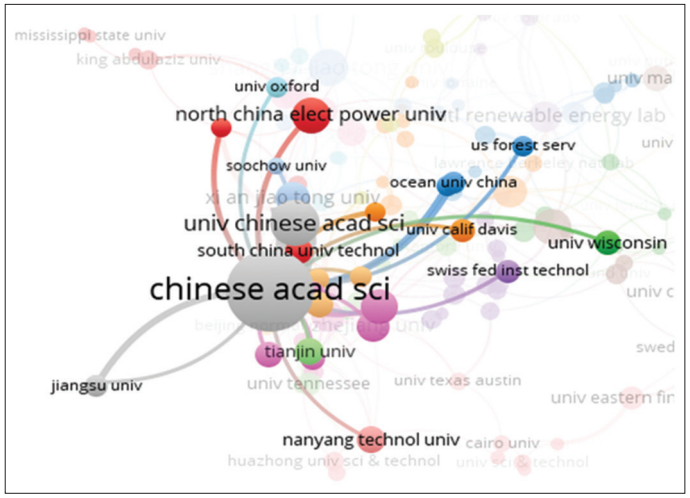
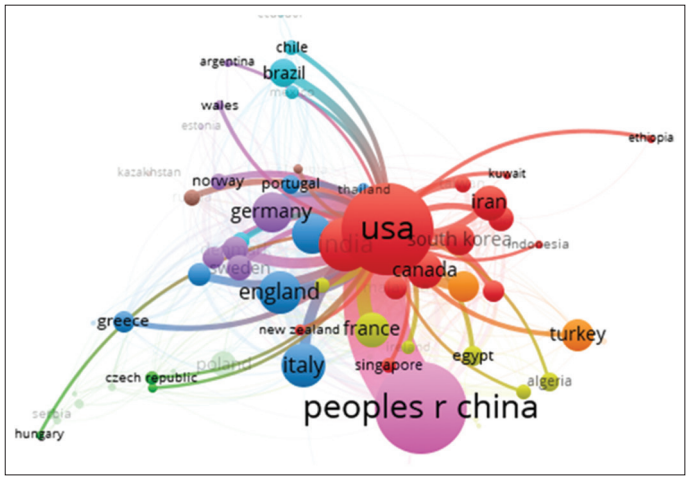


Figure 10: Co-authorships of countries producing articles of the three mains RET



4. CONCLUSIONS

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, care of the environment and the imminent problem of scarcity of fossil resources in a few years, countries such as

the United States and China have given the first signs that it is feasible, viable and effective to use and implement clean and sustainable energy sources. Of all the bibliometric studies carried out in this chapter, it is worth highlighting the participation of thousands of authors interested in contributing knowledge to the subject and achieving the objectives set by countries all over the world about the production of renewable energies. The United States and China have a very dominant role in the production of this subject in the last 10 years, the United States contributed 21.5% and China 15.2% of the total number of publications, justified by the seven research organizations of these countries that are among the top 12 in the world to produce articles on renewable energy.

The countries with the highest production of these energies are those that have the highest rate of citation of articles referring 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 to have research organizations with high production performance. Thanks to this chapter, it was possible to describe graphically the performance of the main institutions and/or research organizations producing articles, the trend of the publications and the contribution made by each country in the world; with this it was obtained that the greatest growth of the production of publications took place from the year 2010; from this moment the investigation about Wind Energy and Biomass begins to grow suddenly obtaining equal records and for the moment superior to the publications about Solar Energy. The analyses provided in this work will allow us to know the status of studies of renewable energy, for further research and development of these technologies.

Despite the need to strengthen national and international policies for the use of renewable energies, the acceleration of the deployment of solar and wind energy makes evident a global motivation to invest in it, so many projects are under development. Substantial global growth is expected in China, India, Europe and North America. In addition, very high growth rates in number of publications and implementations can be expected in several Latin American countries, particularly Brazil, as well as in new Asian and Eastern European markets. In the medium term some African countries will have an appreciable development, mainly in the whole of North Africa, but also in the south, which will allow the scaling of these countries in the bibliometric indicators studied in this research.

REFERENCES

Afonso, T.L., Marques, A.C., Fuinhas, J.A. (2017), Strategies to make renewable energy sources compatible with economic growth. Energy Strategy Reviews, 18, 121-126.

Amri, F. (2019), Renewable and non-renewable categories of energy consumption and trade : Do the development degree and the industrialization degree. Energy, 173, 374-383.

Arapkoules, N.K., Ponis, S.T., Papadiamantis, P. (2015), Transforming solar thermal collectors into high performance electricity and heat cogeneration units. International Review of Mechanical Engineering, 9(3), 284-290.

Arias-Gaviria, J., Carvajal-Quintero, S.X., Arango-Aramburo S. (2019), Understanding dynamics and policy for renewable energy diffusion in Colombia. Renewable Energy, 139, 1111-1118.

Assali, A., Khatib, T., Najjar, A. (2019), Renewable energy awareness among future generation of palestine. Renewable Energy, 136, 254-263.

ASTM G-173-03. (2002), Terrestrial Reference Spectra for Photovoltaic Performance Evaluation. West Conshohocken: American Society for Testing Materials (ASTM) International.

Azhgaliyeva, D. (2019), Energy storage and renewable energy deployment: Empirical evidence from OECD countries. Energy Procedia, 158, 3647-3651.

Baruah, D.C., Enweremadu, C.C. (2019), Prospects of decentralized renewable energy to improve energy access : A resource-inventory-based analysis of South Africa. Renewable and Sustainable Energy Reviews, 103, 328-341.

Bayulgen, O., Benegal, S. (2019), Green priorities : How economic frames a ff ect perceptions of renewable energy in the United States. Energy Research and Social Science, 47, 28-36.

Benedek, J., Sebestyén, T., Bartók, B. (2018), Evaluation of renewable energy sources in peripheral areas and renewable energy-based rural development. Renewable and Sustainable Energy Reviews, 90, 516-535.

Bistline, J., Nidhi, S., David, Y. (2019), The economic geography of variable renewable energy and impacts of trade formulations for renewable mandates. Renewable and Sustainable Energy Reviews, 106, 79-96.

Bradshaw, A. (2017), Regulatory change and innovation in Latin America: The case of renewable energy in Brazil. Utilities Policy, 49, 156-164.

Braungardt, S., Veit, B., Jana, Z., Lex, B. (2019), How to include cooling in the EU renewable energy directive ? Strategies and policy implications. Energy Policy, 129, 260-267.

Bulut, U., Gonul, M. (2018), Renewable energy in Turkey : Great potential, low but increasing utilization, and an empirical analysis on renewable energy-growth nexus. Energy Policy, 123, 240-250.

Burcu, O., Ozturk, I. (2019), Renewable energy consumption-economic growth nexus in emerging countries : A bootstrap panel causality test. Renewable and Sustainable Energy Reviews, 104, 30-37.

Camargo-Ramirez, L., Valdes, J., Yunesky-Masip, M., Wolfgang, D. (2018), Assessment of on-site steady electricity generation from renewable assessment steady electricity generation from renewable the energy sources in chile energy sources in chile assessing the of using masip heat maci. Energy Procedia, 158, 1099-1104.

Canaria, G., Pedro, C., Henrik, L. (2018), Smart renewable energy penetration strategies on Islands : The case of Gran Canaria. Energy, 162, 421-443.

Cepeda, J., Sierra, A. (2016), Aspectos Que Afectan La Eficiencia En Los Paneles Fotovoltaicos y Sus Potenciales Soluciones, 10. Thesis.

Chen, Y., Jincai, Z., Zhizhu, L., Zheng, W., Haibin, X. (2019), Exploring the effects of economic growth, and renewable and non-renewable energy consumption on China's CO_2 emissions: Evidence from a regional panel analysis. Renewable Energy, 140, 341-353.

Chen, Y., Zheng, W., Zhangqi, Z. (2019), CO_2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. Renewable Energy, 131, 208-216.

Clauser, C., Markus, E. (2018), The renewables cost challenge: Levelized cost of geothermal electric energy compared to other sources of primary energy - review and case study. Renewable and Sustainable Energy Reviews, 82, 3683-3693.

Delucchi, M.A., Jacobson, M.Z. (2013), Meeting the world's energy needs entirely with wind, water, and solar power. Bulletin of the Atomic Scientists, 69(4), 30-40.

Denholm, P., Margolis, R.M. (2007), Evaluating the limits of solar

photovoltaics (PV) in electric power systems utilizing energy storage and other enabling technologies. Energy Policy, 35(9), 4424-4433.
Ding, W., He, L., Zewudie, D., Zhang, H., Zafar, B.T. (2019), Gender and renewable energy study in tibetan pastoral areas of China. Renewable Energy, 133, 901-913.
Djørup, S., Thellufsen, H.Z., Sorknæs, P. (2018), The electricity market in a renewable energy system. Energy, 162, 148-157.
Draycott, S.B. (2019), Capture and simulation of the ocean environment for offshore renewable energy. Renewable and Sustainable Energy Reviews, 104, 15-29.
Dubey, S., Sarvaiya, N.S., Bharath, S. (2013), Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world - a review. Energy Procedia, 33, 311-321.
Eitan, A., Herman, L. (2019), Community - private sector partnerships in renewable energy. Renewable and Sustainable Energy Reviews, 105, 95-104.
Eren, B.M., Nigar, T., Gokmenoglu, K.K. (2019), The impact of financial development and economic growth on renewable energy consumption : Empirical analysis of India. Science of the Total Environment, 663, 189-197.
Fadly, D., Fontes, F. (2019), Geographical proximity and renewable energy diffusion : An empirical approach. Energy Policy, 129, 422-435.
Franceschet, M. (2010), The difference between popularity and prestige in the sciences and in the social sciences: A bibliometric analysis. Journal of Informetrics, 4(1), 55-63.
Frombo, F., Minciardi, R., Robba, M., Rosso, F., Sacile, R. (2016), A dynamic decision model for the optimal use of forest biomass for energy production. Energy Systems, 7(4), 615-635.
Hache, E. (2018), Do renewable energies improve energy security in the long run ? International Economics, 156, 127-135.
Hamilton, L.C., Bell, E., Hartter, J., Salerno, J.S. (2018), A change in the wind? US public views on renewable energy and climate compared. Energy, Sustainability and Society, 8(11), 1-13.
Hanh, K., Makoto, K. (2019), Renewable energy consumption, carbon emissions, and development stages : Some evidence from panel cointegration analysis. Renewable Energy, 132, 1049-1057.
Hansen, K., Mathiesen, B.V., Skov, I.R. (2019), Full energy system transition towards 100% renewable energy in Germany in 2050. Renewable and Sustainable Energy Reviews, 102, 1-13.
Harjanne, A., Korhonen, J.M. (2019), Abandoning the concept of renewable energy. Energy Policy, 127, 330-340.
Haufe, M.C., Ehrhart, K.M. (2018), Auctions for renewable energy support - suitability, design, and first lessons learned. Energy Policy, 121, 217-224.
Helmisaari, H.S., Makkonen, K., Kellomäki, S., Valtonen, E., Mälkönen, E. (2002), Below- and above-ground biomass, production and nitrogen use in scots pine stands in Eastern Finland. Forest Ecology and Management, 165, 317-326.
Hentschel, M., Ketter, W., Collins, J. (2018), Renewable energy cooperatives : Facilitating the energy transition at the port of Rotterdam. Energy Policy, 121, 61-69.
Hernández-Escobedo, Q., Perea-Moreno, A.J., Manzano-Agugliaro, F. (2018), Wind energy research in Mexico. Renewable Energy, 123, 719-729.
Hou, J., Cao, M., Liu, P. (2018), Development and utilization of geothermal energy in China: Current practices and future strategies. Renewable Energy, 125, 401-412.
Hu, R., Skea, J., Hannon, M.J. (2018), Measuring the energy innovation process: An indicator framework and a case study of wind energy in China. Technological Forecasting and Social Change, 127, 227-244.
Iqbal, T., Dong, C., Lu, Q., Ali, Z., Khan, I., Hussain, Z., Abbas, A. (2018), Sketching Pakistan's energy dynamics: Prospects of biomass energy. Journal of Renewable and Sustainable Energy, 10(2), 023101.
Jacobson, M.Z., Delucchi, M.A., Bauer, Z.A., Goodman, S.C., Chapman, W.E., Cameron, M.A., Bozonnat, C., Chobadi, L., Clonts, H.A., Enevoldsen, P., Erwin, J.R., Fobi, S.N., Goldstrom, O.K., Hennessy, E.M., Liu, J., Lo, J., Meyer, C.B., Morris, S.B., Moy, K.R., O'Neill, P.L., Petkov, I., Redfern, S., Schucker, R., Sontag, M.A., Wang, J., Weiner, E., Yachanin, A.S. (2017), 100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world. Joule, 1, 108-121.
Kartite, J., Cherkaoui, M. (2019), Study of the different structures of hybrid systems in renewable energies: A review. Energy Procedia, 157, 323-330.
Keček, D., Mikulić, D., Lovrinčević, Ž. (2019), Deployment of renewable energy : Economic effects on the croatian economy. Energy Policy, 126, 402-410.
Keck, F., Lenzen, M., Vassallo, A., Li, M. (2019), The impact of battery energy storage for renewable energy power grids in Australia. Energy, 173, 647-657.
Kim, J., Park, S.Y., Lee, J. (2018), Do people really want renewable energy ? Who wants renewable energy ? Discrete choice model of reference-dependent preference in South Korea. Energy Policy, 120, 761-770.
Koenig, J.B. (1970), Geothermal exploration in the Western United States. Geothermics, 2, 1-13.
Kreuz, S., Felix, M. (2018), Measuring the cost of renewable energy in Germany. The Electricity Journal, 31(4), 29-33.
Lewis, N.S. (2007), Toward cost-effective solar energy use. Science, 315(5813), 798-801.
Lin, B., Chen, Y. (2019), Does electricity price matter for innovation in renewable energy technologies in China? Energy Economics, 78, 259-266.
Liu, J. (2019), China's renewable energy law and policy : A critical review. Renewable and Sustainable Energy Reviews, 99, 212-219.
Liu, W., Xingping, Z., Feng, S. (2019), Does renewable energy policy work ? Evidence from a panel data analysis. Renewable Energy, 135, 635-642.
Lin, B., Zhu, J. (2019), The role of renewable energy technological innovation on climate change: Empirical evidence from China. Science of the Total Environment, 659, 1505-1512.
Mamvura, T.A., Pahla, G., Muzenda, E. (2018), Torrefaction of waste biomass for application in energy production in South Africa. South African Journal of Chemical Engineering, 25, 1-12.
Mascarós, M.V. (2016), Gestión Del Montaje de Instalaciones Solares Fotovoltaicas. Madrid: Ediciones Paraninfo.
Mekhilef, S., Saidur, R., Safari, A. (2011), A review on solar energy use in industries. Renewable and Sustainable Energy Reviews, 15(4), 1777-1790.
Miller, L., Rupp, C. (2018), A review of energy storage fi nancing - learning from and partnering with the renewable energy industry. Journal of Energy Storage, 19, 311-319.
Moorthy, K., Patwa, N., Saravanan, V., Gupta, Y. (2019), Breaking barriers in deployment of renewable energy. Heliyon, 5(1), 1-23.
Narayanan, A., Mets, K., Strobbe, M., Develder, C. (2019), Feasibility of 100% renewable energy-based electricity production for cities with storage and flexibility. Renewable Energy, 134, 698-709.
Navratil, J., Picha, K., Martinat, S., Bucheckers, M., Svec, R., Brezinova, M., Knotek, J. (2019), Visitors' preferences of renewable energy options in "green" hotels. Renewable Energy, 138, 1065-1077.
Navratila, J., Picha, K., Buchecker, M., Martinat, S., Svec, R., Brezinova, M., Knotek, J. (2019), A conceptualization of renewable energy-powered industrial cluster development in Indonesia. Energy Procedia, 156, 7-12.
Nguyen, P.A., Malcolm, A., Nguyen, L.T. (2019), The development and

cost of renewable energy resources in Vietnam. Utilities Policy, 57, 59-66.
Obeng-Darko, N.A. (2019), Why Ghana will not achieve its renewable energy target for electricity. Policy, legal and regulatory implications. Energy Policy, 128, 75-83.
Olson-Hazboun, S.K., Howe, P., Leiserowitz, A. (2018), The influence of extractive activities on public support for renewable energy policy. Energy Policy, 123, 117-126.
Overland, I. (2019), The geopolitics of renewable energy : Debunking four emerging myths. Energy Research and Social Science, 49, 36-40.
Ozturk, I., Bilgili, F. (2015), Economic growth and biomass consumption nexus: Dynamic panel analysis for Sub-Sahara African countries. Applied Energy, 137, 110-116.
Pietrosemoli, L., Rodríguez-Monroy, C. (2019), The venezuelan energy crisis : Renewable energies in the transition towards sustainability. Renewable and Sustainable Energy Reviews, 105, 415-426.
Pina, A., Baptista, P., Silva, C., Ferrão, P. (2014), Energy reduction potential from the shift to electric vehicles: The Flores island case study. Energy Policy, 67, 37-47.
Reboredo, J.C., Ugolini, A. (2018), The impact of twitter sentiment on renewable energy stocks. Energy Economics, 76, 153-169.
Ribeiro, F., Ferreira, P., Araújo, M., Braga, A.C. (2018), Modelling perception and attitudes towards renewable energy technologies. Renewable Energy, 122, 688-697.
Sakellariou, N. (2017), Engineers and social acceptance of renewable energy [Opinion]. IEEE Technology and Society Magazine, 36(4), 18-20.
Sarmeinto, I., Cardenas, Y., Valencia, G. (2017), Análisis cienciométrico de la investigación de sistemas fotovoltaicos integrados a edificios desde el año 2000 a 2017. Revista Espacios, 38(47), 29-40.
Scaramuzzino, C., Garegnani, G., Zambelli, P. (2019), Integrated approach for the identification of spatial patterns related to renewable energy potential in European territories. Renewable and Sustainable Energy Reviews, 101, 1-13.
Schumacher, K., Krones, F., Mckenna, R., Schultmann, F. (2019), Public acceptance of renewable energies and energy autonomy : A comparative study in the French, German and Swiss Upper Rhine region. Energy Policy, 126, 315-332.
Selosse, S., Garabedian, S., Ricci, O., Maïzi, N. (2018), The renewable energy revolution of Reunion Island. Renewable and Sustainable Energy Reviews, 89, 99-105.
Shin-Li, L. (2019), Integrating heuristic time series with modi fi ed grey forecasting for renewable energy in Taiwan. Renewable Energy, 133, 1436-1444.
Svoboda, K., Andrew, I., Hampson, J., Galambosi, B., Asakawa, Y. (1999), Biomass production, essential oil yield and composition of *Myrica gale* L. harvested from wild populations in Scotland and Finland. Flavour and Fragrance Journal, 13(6), 367-372.
Sweerts, B., Dalla-Longa, F., van der Zwaan, B. (2019), Financial de-risking to unlock Africa's renewable energy potential. Renewable and Sustainable Energy Reviews, 102, 75-82.
Trainer, T. (2017), Some problems in storing renewable energy. Energy Policy, 110, 386-393.
Umar, T. (2017), Geothermal energy resources in Oman. Proceedings of the Institution of Civil Engineers - Energy, 171, 37-43.
Urban, F., Wang, Y., Geall, S. (2018), Prospects, politics, and practices of solar energy innovation in China. The Journal of Environment and Development, 27(1), 74-98.
Washburn, C., Romero, M.P. (2019), Measures to promote renewable energies for electricity generation in Latin American countries. Energy Policy, 128, 212-222.
Ylipulli, J., Suopajärvi, T., Ojala, T., Kostakos, V., Kukka, H. (2014), Municipal WiFi and interactive displays: Appropriation of new technologies in public urban spaces. Technological Forecasting and Social Change, 89, 145-160.
York, R., Bell, S.E. (2019), Energy transitions or additions ? Why a transition from fossil fuels requires more than the growth of renewable energy. Energy Research and Social Science, 51, 40-43.
Yuan, X., Lyu, Y., Wang, B., Liu, Q.,Wu, Q. (2018), China's energy transition strategy at the city level : The role of renewable energy. Journal of Cleaner Production, 205, 980-986.
Zeng, Y., Guo, W., Zhang, F. (2019), Comprehensive evaluation of renewable energy technical cooling plans based on data envelopment analysis. Energy Procedia, 158, 3583-3588.
Zerrahn, A., Schill, W., Kemfert, C. (2018), On the economics of electrical storage for variable renewable energy sources. European Economic Review, 108, 259-279.
Zhang, D., You, P., Liu, F., Zhang, Y., Zhang, Y., Feng, C. (2018), Regulating cost for renewable energy integration in power grids. Global Energy Interconnection, 1(5), 544-551.
Zhou, E., Cole, W., Frew, B. (2018), Valuing variable renewable energy for peak demand requirements. Energy, 165, 499-511.
Zhou, P., Tang, J., Mou, J., Zhu, B. (2016), Effect of impeller trimming on performance. World Pumps, 2016(9), 38-41.