Optimization of Hybrid Renewable Energy Systems for Power Generation: A Bibliometric Review

Yamilet González Cusa
Industrial Engineering Program, Polytechnic School, Federal University of Bahia (UFBA), Salvador, State of Bahia, Brazil

Jorge Laureano Moya Rodríguez
Industrial Engineering Program, Polytechnic School, Federal University of Bahia (UFBA), Salvador, State of Bahia, Brazil

Silvio Alexandre Beisl Vieira de Melo
Chemical Engineering Department, and Interdisciplinary Center on Energy and Environment, Federal University of Bahia, Salvador, State of Bahia, Brazil.

Ednildo Andrade Torres
Mechanical Engineering Department, and Interdisciplinary Center on Energy and Environment, Federal University of Bahia, Salvador, State of Bahia, Brazil.

Abstract

The use of Hybrid Power Generation Systems through renewable sources has been gaining prominence, since it is a way to reduce the dependence on fossil fuels, contributing to the reduction of pollutant gas emissions to the environment. Due to the higher operational complexity, the multiplicity of options and constant improvement of these units, how to optimize these systems is still a subject of present studies. Considering the attention that this topic has received from the academic community, the challenges for mapping and identifying the relevant literature, this article provides a macroscopic view of the scientific literature on the Optimization of Hybrid Renewable Energy Systems (HRES) for energy generation, through analysis bibliometric. The research was developed using the Web of Science database, obtaining a total of 439 articles between 2010 and 2020, where the results were interpreted through the VOSviewer software. The results showed that the number of related publications is gradually increasing, with India as the leading country. The University of Malaya is the institution with a higher number of registers, with 14 entries. Most publications fit into the "Energy Fuels" category, with the magazines "Renewable Sustainable Energy Reviews" and "Renewable Energy" as the most influential in terms of the number of publications, as well as the United States and China are the countries with most research collaboration. Besides, the most cited articles and the recurrence and distribution of keywords indicate the future directions of research. In short, this study contributes valuable information to researchers on the topic.

Keywords: Hybrid renewable energy systems; Hybrid PV/wind/diesel energy system; Optimization, Bibliometric analysis.

1. Introduction

The quick depletion of fossil fuels on a global level has demanded an urgent development of alternative energy sources to satisfy the crescent requirement of energy. One of the main reasons for the use of clean energy sources to electricity generation is the decrease in the dependence on fossil fuels, which increments the effects of global warming with alarming climate changes generating negative environmental impacts during the last decades (Bukar and Tan 2019).

In the present times, renewable energy sources as solar, wind, hydro and biomass energy have received significant attention to the use of electricity in several geographic locations around the world (Faccio et al. 2018). These sources not only decrease carbon dioxide (CO_2) emissions, reducing the necessity to energy generation from fossil fuels, but also provide an energy system more capable of handling failures and less exposure to fluctuating fuel prices (Movahediyan and Askarzadeh 2018). Despite the uncountable advantages of renewable energy sources, its intermittent nature results in the necessity to integrate these generation systems in a suitable combination for a reliable system, constituting a hybrid system based on renewable energy sources (Anoune et al. 2018).

HRES can consist of a converge renewable energy system with a wind turbine, photovoltaic panel, hydro turbine, fuel cells and other elements as conventional diesel generator, microturbine and storage devices like a battery, and this system can be all or just part of them (Bhandari et al. 2015). According to Ferrari et al. (2018), hybrid energy generation systems are an interesting solution to the electricity in remote regions, outside of the coverage of users. Considering the extension of the central electrical grid to those remote geographical regions, with a low population density is not financially viable and practicable (Ogunjuyigbe et al. 2016).

Due to the existence of several technologies and energy systems inside of the HRES, the management and optimization of these systems are highly relevant (Mehrpooya et al. 2018). The HRES optimization problem can be solved through the simultaneous solution of three subproblems (synthesis, design and operations problems), which is already done in other engineering problems to reach a satisfactory result. According to Kaldellis (2010), the synthesis problem consists of defining the type of components that will constitute the HRES; the design problem consists of sizing the components of the system and the operation problem consists of defining an operation strategy that attends with the restrictions defined by the final purpose of the system.

As pointed out by Rahman et al. (2016), the optimization of a hybrid energy system to comply with the charge requirements with minimums investment and operations costs is one of the main challenges of the system. Thus, it is absolutely important that the designers find an ideal optimization technique to the sizing of the system with celerity and accuracy, ensuring that the hybrid system might be able to function in ideal conditions in terms of energy investment and reliability (Zhou et al. 2010). Over the years, lots of research in the literature has been using optimization methods to configure a satisfactory HRES in remote areas.

One of the optimization methodologies to the energy system is the usual traditional methods, as well as the artificial intelligence methods, hybrid methods, and the use of Software tools (Lian et al. 2019).

In the last years, the scientific production has been increasing considerably, making it even more difficult for researchers to follow the relevant literature in their field (Zupic and Čater 2015). In this sense, this article aims to provide a macroscopic view of the current scientific literature about the Optimization of Hybrid Renewable Energy Systems for energy generation, through analysis bibliometric. Also, this paper provides valuable information that can support the scientific community to identify the relevant perspectives and issues related to the current state of development about this topic. The article is structured in three sections: methodology approach used in the bibliometric analysis; the results and discussion section, and the final thoughts.

2. Methodology

The bibliometric analysis was used to analyze and to identify relevant aspects of international scientific production on Optimization of Hybrid Renewable Energy Systems published between 2010 and 2020. It described as an applied statistic method used to assess and quantify the number and trend increase of a specific subject (Mao et al. 2018). The analysis with a focus on bibliometric parameters enables researchers to examine the bibliographic material from an objective and quantitative perspective, making it useful in organizing information on a specific knowledge area (Castillo-Vergara et al. 2018). This type of analysis can support the researchers who evaluate the progress of scientific activity to identify relevant issues both in research carried out and in evolution (Montero-Díaz et al. 2018). Besides that, this analysis has been understood as more objective and more reliable than traditional review methods (Weinand 2020).

In order to write this article and define a research workflow, based on bibliometric methods proposed by Zupic and Čater (2015), this study fits our reality. Below, we present five of its steps in Figure 1.

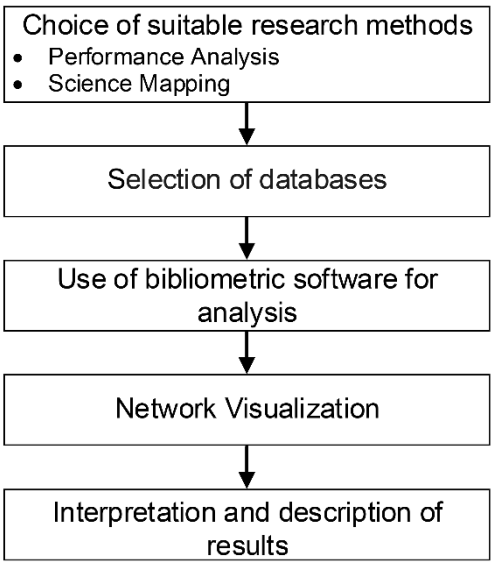

Figure 1. Workflow for bibliometric surveys

2.1 Choice of suitable research methods

The bibliometric analysis has two uses: performance analysis and science mapping (Cobo et al. 2011). The performance analysis seeks to evaluate the characteristics of scientific production, such types, languages, journals, and countries, based on bibliographic data to determine the trends or critical or critical points in a given research area. On the other hand, the science mapping aims to show the structural aspects of scientific fields (Börner et al. 2003; Hou et al. 2015). The analysis of the corpus was done in two stages: the performance analysis and science mapping analysis.

2.1.1 Performance analysis

At this stage, we analyzed some aspects as the number of publications produced per year, languages used by the authors, type of document, distribution of productions by countries, institutions and authors and categories covered. Besides, the most influential magazines and publications are also subject to analysis.

Bibliometric indicators are highly useful to represent the bibliographic material, providing a representative and informative perspective of the data (Cancino et al. 2017). This study uses the entire number of articles and citations to measure its productivity and influence (Cancino et al. 2017), as well as the impact factor (IF) and the H index. The impact factor constitutes a useful indicator to measure the quality of a magazine, while the H index measures the productivity and the impact of the researches published by scientists and scholars (Mao et al. 2015). The H index is adopted to measure the author's influence, while the IF is used to evaluate the magazines (Hou et al. 2015).

2.1.2 Science mapping

At the science mapping stage, we used the co-author analysis, as well as the co-citation and co-word analysis, being those techniques considered the most useful to the development of the science mapping (Cobo et al. 2011). Initially, we developed the analysis of the authors and their affiliations (co-author analysis) between 27 most productive countries. The co-author analysis of scientific publications is assumed to be a collaborative measure, reflecting stronger social ties than other kinship measures, making it suitable for examining social networks (Zupic and Čater 2015).

Then, co-citation analysis is performed, which is considered the most used and validated bibliometric method, connecting documents, authors, or magazines (Zupic and Čater 2015). Co-citation is the frequency that two units are cited together and can identify the knowledge base of a topic/research field and its intellectual structure (Leung et al. 2017). Specifically, it analyzed the co-citation of authors (ACA) aiming to identify relevant authors and connect them through citation entries (White and McCain 1998).

After all, the co-word analysis is performed, which constitutes one of the most used techniques to execute the content analysis, considering that the researchers use expressions and keywords that indicate the central literature central content as a research object (Du et al. 2014). Thus, the principal trends and changes that happen in scientific research, inside of a specific area, can be analyzed from a quantitative point of view. This study considers the keyword in titles and abstracts of publications, aiming to identify relevant aspects of the research in a specific field (Mao et al. 2018). In addition to relating the distribution of keywords according to the categories research subjects, purposes, methods and research areas (Gao et al. 2016).

2.2 Selection of databases

Aiming to verify how the scientific production has developed the research field related to the Optimization of Hybrid Renewable Energy Systems, it was carried out a research in the main collection of Clarivate

Analytics Web of Science database, which constitutes a selective list of journals and conference proceedings, with indexing coverage from 1900 to the present day (Clarivate_Analytics 2020). The chosen database functions as a research mechanism, since it is the most accepted database used for the analysis of scientific publications (Van Nunen et al. 2018; Yang et al. 2013). Besides, this database is compatible with the VOSviewer bibliometric analysis software, transferring abstracts, references, citations, authors, institutions, countries, among others (De Carvalho et al. 2019).

In order to seek the publications, the keywords used were "Hybrid renewable energy system", "Hybrid PV/wind/diesel energy system", "Optimization", using the boolean operator "OR" between the first and the second term and the operator "AND" between the second and the third term, so, in this order, articles on "Optimization" would be shown, both in the "Hybrid renewable energy system" or "Hybrid PV/wind/diesel energy system" approach. The term "Hybrid renewable energy system" was specified in the field title, for search in the titles of publications, while for the terms "Hybrid PV/wind/diesel energy system" and "Optimization" the field topic was described, including the analysis in the title, abstract and keywords of publications. The defined time interval was 2010-2020 and the search was refined by document types (Article or Review).

2.3 Use of bibliometric software for analysis

The data obtained from Web of Science were removed to be processed by the science mapping software VOSviewer, and for making graphs and tables, Microsoft Excel software was used. These procedures were carried out to analyze the bibliographic performance and the evolution of the research field studied through science mapping.

The VOSviewer software (version 1.6.15) allows the creation, visualization and exploration of maps with based on bibliometric network data (Van Eck. and Waltman 2020). VOSviewer can be used to author construct maps or maganized based on co-citation data or to construct maps of keywords based on co-occurrence data (VOSviewer 2020), being its main functionality to exhibit large bibliometric maps in an easy to interpret way (Van Eck and Waltman 2010). In addition, the main advantage of this program over most information technology programs available to bibliometric mapping is its incidence on the graphical representations of maps (Castillo-Vergara et al. 2018).

2.4 Network Visualization

Based on a long-distance analysis, the network visualization through maps allows us to identify groups of related items more easily (Van Eck and Waltman 2010). In the network visualization, the items are represented by its label and circle. Its size is determined by the weight of the item and the color of an item is determined by the cluster to which the item belongs. Also, the lines between items represent links (Van Eck. and Waltman 2020). Network analysis allows us to perform a statistical analysis on the map produced in the posterior stage (Cobo et al. 2011).

2.5 Interpretation and description of results

In this stage, the results obtained from the analysis of bibliographic performance and science mapping are interpreted. In the interpretation step, the analyst looks to discover and extract useful knowledge that could be used to make decisions on which policies to implement (Cobo et al. 2011).

3. Results and discussion

In this section, it will present the results of bibliographic performance and science mapping analysis.

3.1 Bibliographic performance analysis

3.1.1 Distribution of publications by type of publication, language and year

The data used in this study was obtained on May 18, 2020, with a total of 439 publications related to the Optimization of Hybrid Renewable Energy Systems. In these publications, it was identified 389 research articles that represent 89% of all publications, and 50 review articles, which represents 11%. We identify that most publications were written in English, with a total of 438 articles in this language, while only one was written in Russian, showing the role of English as a tool to disclose scientific research even in countries where English is not a native-language as China, India, Italy, and Spain

In order to verify the temporal evolution of publications, we present the number of articles published per year in Figure 2. According to the graph, the number of publications between 2010 and 2020 has shown an increasing trend. In the past five years, the number has grown by 14% per year on average. This increase may be related to the development of renewable energies and the incentive actions for their greater use. In the period analyzed, 2019 was the year with the largest number of records, with a total of 111. As of May 2020, 44 papers have been published. The annual growth pattern may indicate a trend of continuity in the increase in research in the area in subsequent years.

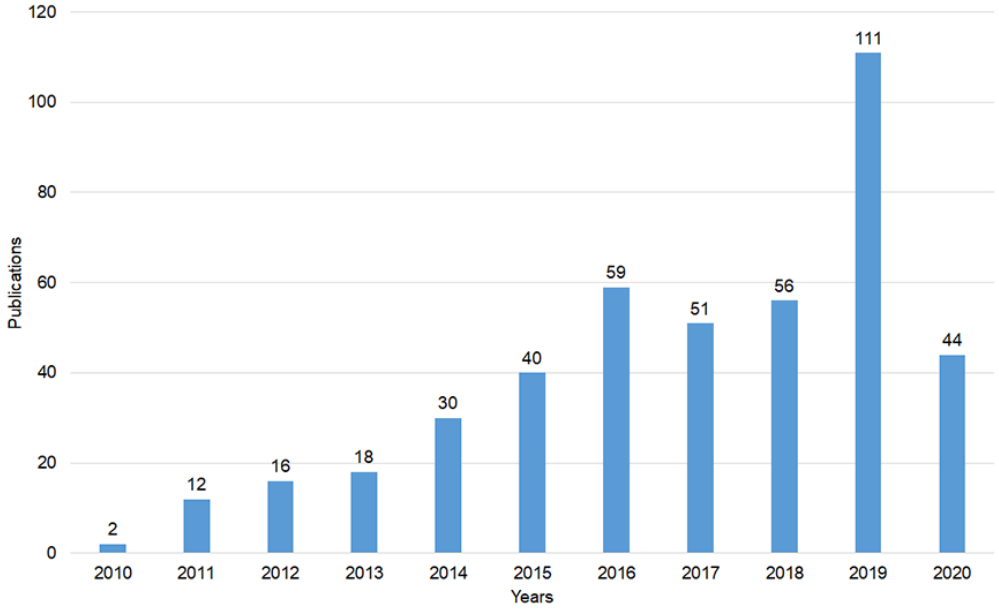

Figure 2. Distribution of publications by year

3.1.2 Distribution of publications by countries, institutions and authors

In this period, 72 countries have been contributing to articles on Optimization of Hybrid Renewable Energy Systems. The 10 countries with the largest number of records developed in the analyzed period are responsible for 74% of scientific production, with 323 of 439 publications. Among these countries, seven belong to the Asian continent, two to North America and one to Europe. The country with the largest number of records is India with a total of 69 publications, followed by Iran and China with 42 articles each, and the United States and Malaysia with 28 and 27 studies developed respectively. The number of articles on the topic shows that countries such as India, Iran, China, United States and Malaysia have shown more interest in the optimization of hybrid systems compared to other countries. An analysis of the annual behavior of the number of publications from the five most productive countries on the topic is presented in Figure 3.

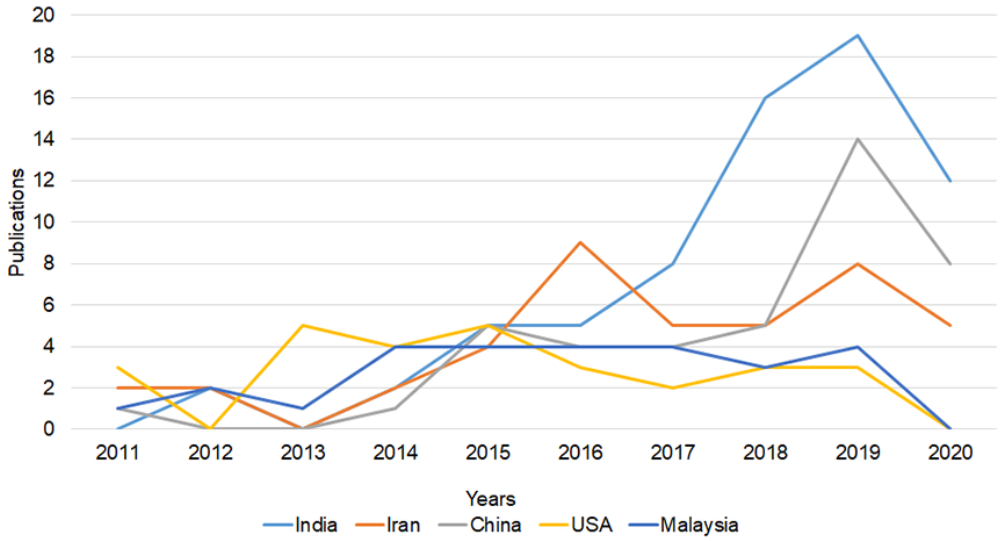

Figure 3. Distribution of the number of publications in the study period

Over the years, India has shown a noticeable increment of the number of scientific productions, in comparison with other countries, achieving the number maximum of publications in 2019, with 19 registers. Besides, India is considered the fourth largest renewable energy market, and today 35% of the energy produced in the country comes from renewable sources and still has a goal of reaching 175 gigawatts of renewable energy capacity by 2022 (REN21 2019). Recently, the renewable energy department in India has seen a notable increase in investment and in the implementation of policies that promote the use of this type of energy, which justifies the efforts in the development of scientific productions on the subject in the country (Das et al. 2019).

Analyzing the annual distribution of publications, we realize that China has presented an increase in the number of publications in the last years, especially in 2019, with 14 registers. The country is leading the global ranking of renewable energy, being considered the largest producer, exporter, and installer of solar and wind technologies in the world (REN21 2019). Recently, it was promulgated in the country several incentive policies on renewable energy sources, promoting their development and use (Lian et al. 2019). In addition, China has established, as part of the actions against climate change, a target of cutting CO_2

emissions per unit of GDP by 60-65% from 2005 to 2030 (X. Zhang et al. 2016). All of these actions and incentives may be conditioning the progressive increase in the number of publications in the country.

Although the fact that Iran has the same number of publications in the period as China, we notice that the country presented higher stability in the number of studies developed over the years, always with an increasing trend, reaching the maximum number of publications (9) in 2016. Due to its geographical position, the country has an enormous potential for the production of different types of renewable energy, considering the installed solar energy with capacity of 39,777 kW, 10,266 MW by hydroelectric plants and 110.1 MW of wind energy (Khojasteh et al. 2018). In addition, the country has comprehensive plans until 2020 for the production of 5 GW of electricity using renewable energy sources (REN21 2019). Therefore, to achieve this goal, it is necessary to develop more renewable energy, which may be linked to the increase in publications.

According to this study, the United States was the fourth country with a higher number of publications about the theme, showing, over the years, a consistency in the number of publications, fluctuating with 3 records per year, on average. Also, the United States occupies the second place in the global ranking of investment in renewable energy, having invested approximately US $ 356 billion in the last decade, which corroborates with the great concern and efforts of the country in the development of research on the subject (REN21 2019).

Malaysia was the fifth country with a higher number of articles, showing from 2014 an increment in the number of records, maintaining stability until today. The country has set a goal of 20% of clean energy generation by 2030, which may have influenced the greater interest in publications on the subject (REN21 2019).

Altogether, 538 different institutions are indicated in the publications. Table 1 lists the 10 most relevant institutions in terms of the number of publications on Optimization of Hybrid Renewable Energy Systems. These institutions have been responsible for 84 (19%) publications so far. Among these institutions, two are from Iran, two from Egypt and two from Spain. Malaysia, Qatar, Saudi Arabia and Nigeria are represented by one institution each. The University of Malaya, located in Malaysia, is the institution that stands out with the largest number of publications, 14 in total. Although countries like India, China and the USA are among the most productive countries as shown above, none of the listed institutions belong to these countries, which may indicate that parts of the total number of publications in these countries are spread over several institutions.

Table 1. Institutions with the largest number of publications on Optimization of Hybrid Renewable Energy Systems

Institutions	Number of publications	Country
University Malaya	14	Malaysia
Qatar University	9	Qatar
University of Tehran	9	Iran
Islamic Azad University	9	Iran
King Saud University	8	Saudi Arabia
Mansoura University	7	Egypt

Menia University	7	Egypt
Federal University Technology	7	Nigeria
Universidad de Cadiz	7	Spain
Universidad de Jaen	7	Spain

Between 2010 and 2020, a total of 1276 authors developed works on Optimization of Hybrid Renewable Energy Systems. Authors with up to five studies published on the topic are classified at Table 2. These authors represent only 1% of the total number of authors and they have contributed with 88 articles. The H index, which measures the impact and productivity of the authors, number of citations, average citations and country, are also exposed. As shown in the table, it was possible to verify that the following authors have the largest number of publications and the highest H-indexes, Eltamaly, Ali M (7 and 6), Mekhilef, Saad (7 and 7), Olatomiwa, Lanre (7 and 6) and Jurado, Francisco (7 and 7). As noted, the relevant authors belong to countries on the European and Asian continents.

Table 2. Authors with the largest number of publications on Hybrid Optimization of Renewable Energy Systems

Authors	Number of publications	Citations	H index	Average of citations	Country
Eltamaly, Ali M	7	125	6	17,86	Egipt
Mekhilef, Saad	7	334	7	47,71	Malaysia
Olatomiwa, Lanre	7	332	6	47,43	Nigeria
Jurado, Francisco	7	234	7	33,43	Spain
Mohamed, Mohamed A	6	112	5	18,67	Egipt
Baredar, Prashant	6	267	5	44,50	India
Bartolucci, Lorenzo	5	44	3	8,80	Italy
Cordiner, Stefano	5	44	4	11,50	Italy
Mulone, Vincenzo	5	44	4	11,50	Italy
Khare, Vikas	5	215	4	43,00	India
Fernández-Ramirez, Luís M	5	105	4	21,00	Spain
Yoo, Chankyoo	5	51	3	10,20	South Korea

3.1.3 Distribution of publications by categories covered and magazines

The 439 articles found about the research topic were grouped into 51 categories covered within the Web of Science. The table 3 shows the five most influential categories in terms of number of publications. As can be seen, the “Energy Fuels” category is the most embracing with a total of 284 records followed by “Green Sustainable Science Technology” with 132 records. The greater number of publications, mainly in these two categories, shows the interest in the optimization of Hybrid Renewable Energy Systems as a way to reduce the dependence on fossil fuels, contributing to the reduction of pollutant gas emissions to the environment. The “Thermodynamics” category is in third place with 70 publications, followed by “Engineering Electrical Electronic” and “Engineering Chemical” with 55 and 30 publications, respectively.

Table 3. Distribution of the number of publications by category

Web of Science categories	Number of publications	%
Energy Fuels	284	64,5
Green Sustainable Science Technology	132	30,0
Thermodynamics	70	15,9
Engineering Electrical Electronic	55	12,5
Engineering Chemical	30	6,8

The articles on Optimization of Hybrid Renewable Energy Systems on the analyzed period were published in 123 different magazines, being an indicative of the dimension and consolidation that the research on the subject has achieved. Journals with until 11 records and their respective impact factors are listed in Table 4. The impact factor is a useful indicator to measure the quality of a magazine (Mao et al. 2015). This article is used to evaluate the relative influence of periodic related to the topic studied. The impact factor for each individual journal was retrieved from the relative official website. These magazines contain 54% of the publications on the subject of study. “Renewable Sustainable Energy Reviews” and “Renewable Energy” constitute the most productive magazines with a total of 36 publications each, followed by the magazines “Energy”, “Energy Conversion and Management” and “Energies” with 33, 24 and 20 articles, respectively. The magazine that recorded the highest impact factor was “Renewable Sustainable Energy Reviews” with 10,556, which indicates greater influence and quality in relation to the others. “Applied Energy”, despite being in eighth place, has the second largest impact factor, 8,426. As shown in the table, most magazines are related to renewable energy and energy sustainability.

Table 4. Magazines with the largest number of publications on Hybrid Renewable Energy System Optimization

Magazines	Impact factor	Number of publications
Renewable Sustainable Energy Reviews	10,556	36
Renewable Energy	5,439	36
Energy	5,53	33
Energy Conversion and Management	7,181	24
Energies	2,676	20
International Journal of Renewable Energy Research	3,12	19
Journal of Renewable and Sustainable Energy	1,511	15
Applied Energy	8,426	15
International Journal of Hydrogen Energy	4,084	15
Solar Energy	4,674	11
Sustainability	2,592	11

The annual behavior of the publications about Optimization of Hybrid Renewable Energy Systems of the five most productive magazines is shown in Figure 4. Until 2014, most articles were published in "Renewable Sustainable Energy Reviews" and "Renewable Energy", which initially shows interest in mainly review studies on sustainable energy. Since 2015 with the Paris Climate Convention agreement, which included limiting global warming to less than 1.5 ℃ and reducing greenhouse gas emissions, the global capacity for renewable energy has been increasing in recent years. to contribute to decarbonization (Weinand 2020). This is visibly noticeable, as from 2015 most of the five magazines increased the number of publications. From 2017 to the current times, magazines such as "Energy" and "Energy Conversion and Management" have been gaining prominence in the number of publications, which shows greater interest in technical, management and energy sustainability aspects of hybrid systems.

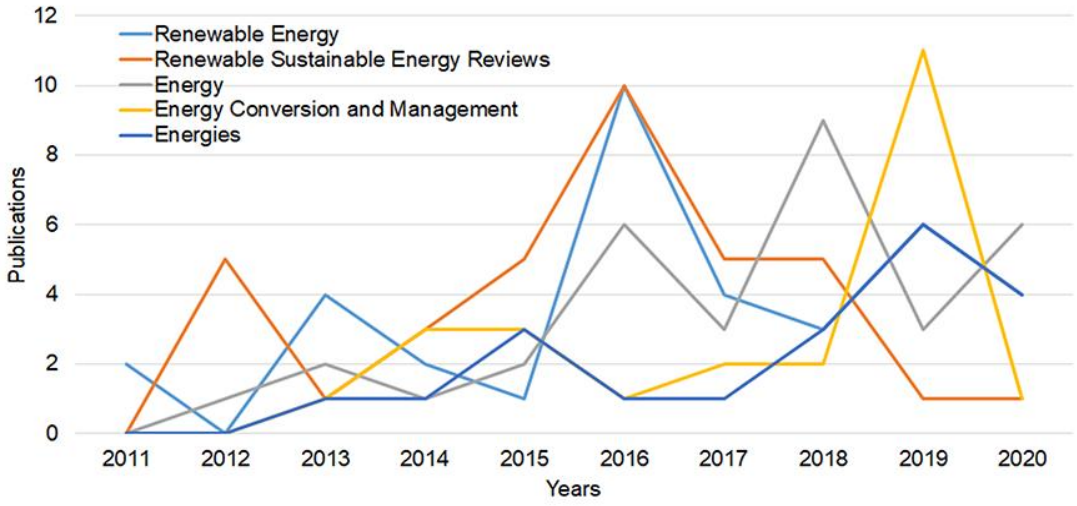

Figure 1. Annual publications about Optimization of Hybrid Renewable Energy Systems from the top five magazines

3.1.4 Publications with the highest number of citations

In order to identify the articles that can be considered the most relevant in the scientific production about Optimization of Hybrid Renewable Energy Systems during the study, we found the 10 most cited articles about the theme, as Table 5 shows.

Table 5. Most cited articles among the scientific contributions on Hybrid Renewable Energy System Optimization

Articles	Year of Publication	Total citations	Citations /year	Authors	Magazine
A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications	2011	351	35,1	(Nehrir et al. 2011)	IEEE Transactions on Sustainable Energy

Hybrid renewable energy systems for power generation in stand-alone applications: A review	2012	333	37	(Bajpai and Dash 2012)	Renewable & Sustainable Energy Reviews
Optimum design of hybrid renewable energy systems: Overview of different approaches	2012	329	36,5	(Erdinc and Uzunoglu 2012)	Renewable & Sustainable Energy Reviews
Review of software tools for hybrid renewable energy systems	2014	281	40,1	(Sinha and Chandel 2014)	Renewable & Sustainable Energy Reviews
Optimal sizing of renewable hybrids energy systems: A review of methodologies	2012	229	25,4	(Luna-Rubio et al. 2012)	Solar Energy
Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: A review	2012	196	21,7	(Fadaee and Radzi 2012)	Renewable & Sustainable Energy Reviews
Solar-wind hybrid renewable energy system: A review	2016	172	34,4	(Khare et al. 2016)	Renewable & Sustainable Energy Reviews
Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach	2014	154	22	(Sharafi and ELMekkawy 2014)	Renewable Energy
Energy management strategies in hybrid renewable energy systems: A review	2016	143	28,6	(Olatomiwa et al. 2016)	Renewable & Sustainable Energy Reviews
Optimization of an off-grid hybrid PV-Wind-Diesel system with different battery technologies using genetic algorithm	2013	143	17,8	(Merei et al. 2013)	Solar Energy

The number of citations is commonly used to verify the impact of a specific article (Mao et al. 2015). However, the measurement of scientific production tends, based on the number of citations, to favor older articles. Since, the number of citations of a publication is highly correlated with the time, considering the date of its publication (Qiu and Chen 2009). For this reason, the articles are also analyzed according to the number of citations per year to adjust the difference in the length of time since their publication. Table 5 shows that the most cited article is entitled "The Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications" with a total of 351 citations since its publication in 2011. However, when analyzing from the number of citations for years, we find that the article entitled "Review of software tools for hybrid renewable energy systems", published in 2014 and which occupies the fourth place in terms of the number of citations, has a higher number of annual citations with an average of 40,1. Considering the articles listed, eight are characterized as review articles and two as articles. In particular, review articles receive more citations than regular research papers, because they summarize the results of many articles (Gao et al. 2016). In general, the ten most relevant articles address aspects such as challenges in the design and management of hybrid renewable energy systems, as well as the main methodologies and techniques for optimizing these systems. Also, most cited articles were published in the top ten of the most relevant magazines: six in "Renewable Sustainable Energy Reviews", one in "Renewable Energy" and two in the magazine "Solar Energy". These works correspond to 22% of the total citations present in the analyzed base, which denotes their relevance and their impact for research in the area.

3.2 Science Mapping Analysis

For the analysis of science mapping on Optimization of Hybrid Renewable Energy Systems, the diagrams of co-authorship, co-citation and co-occurrence of keywords developed by the VOSviewer software are presented.

3.2.1 Co-author network per country

Using VOSviewer software, the cooperation network between countries was created for the production of articles about the Optimization of Hybrid Renewable Energy Systems. This network refers to co-author, where researchers, research institutions, or countries are linked to each other based on the number of publications that are author filiated/written (Pauna et al. 2019). Academic cooperation between countries is significant, as communication between them improves understanding of the topic and the search for innovative solutions, as well as the exchange of experiences through international cooperation (Gao et al. 2016). Considering the 72 countries that have contributed to the study topic, 27 registered, leastwise, five publications on the theme linked in a network or map shown in Figure 5. Also, the size of the circles represents the number of publications, and the thickness of the links represents the strength of collaboration and colors represent collaboration clusters (Van Nunen et al. 2018).

As Figure 5 shows, the three most representative groups correspond to those developed around the United States (red cluster), Malaysia (green cluster) and China (blue cluster) with 10, 7 and 5 member countries respectively, with two clusters identified as smaller ones around Turkey and Iran. We found out that different clusters are formed around the most productive countries in terms of publication production

(Zheng et al. 2016). As noted, the countries that have the most cooperation, in terms of publications with other countries, are the United States and China, with a total of 12 links each. According to the consistency of the collaborations, the most representative is Saudi Arabia with Egypt, China with Egypt, and Malaysia with Nigeria, constituting a total of articles published in co-authorship of 10, 7, and 6 respectively. Despite India being the country with the largest number of publications, it shows a less expressive number of collaborations in HRES Optimization studies when compared to other countries with the lowest number of publications. We observed that a wide range of collaboration already exists among many countries. However, it can also be seen that there are still possibilities for the development of exchange and cooperation in this field. For example, in the past 10 years, leading countries such as India have had no cooperation with countries such as Iran, China, the United States, and Malaysia. Iran has also had no cooperation with the United States even though the two stand out in research on the theme. In this sense, research funding agencies, from different countries, must work together to offer more opportunities for joint research, enabling greater transfers of knowledge and technologies.

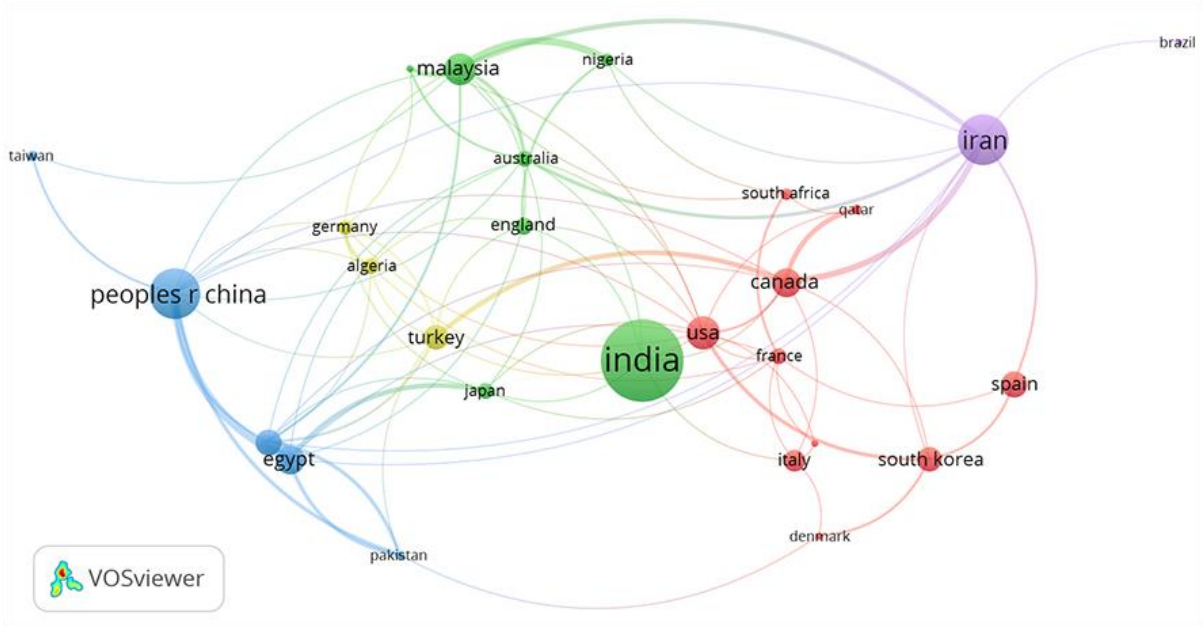

Figure 2. Cooperation network between countries in the production of studies on Optimizing Hybrid Renewable Energy Systems

3.2.2 Co-citation network by authors

Analysis of co-citation of authors aims to analyze the intellectual structure of a given area or group of researchers, showing its social, cognitive structure and its research domain (McCain 1990). It can be defined as the analysis of a set of authors structurally organized in a social and cognitive network of a given domain (Grácio and Oliveira 2014).

Figure 6 shows the network of co-citation relationships of authors. The cut-off criterion was a minimum number of twenty citations, which led to a co-citation network of 100 authors (nodes). The size of the circles represents the number of times the author has been cited and the link between two nodes indicates a co-citation relationship, the greater the thickness of the link the greater the frequency of co-citation

between the authors who links and the node color represents the thematic areas that are similar (Fabregat-Aibar et al. 2019).

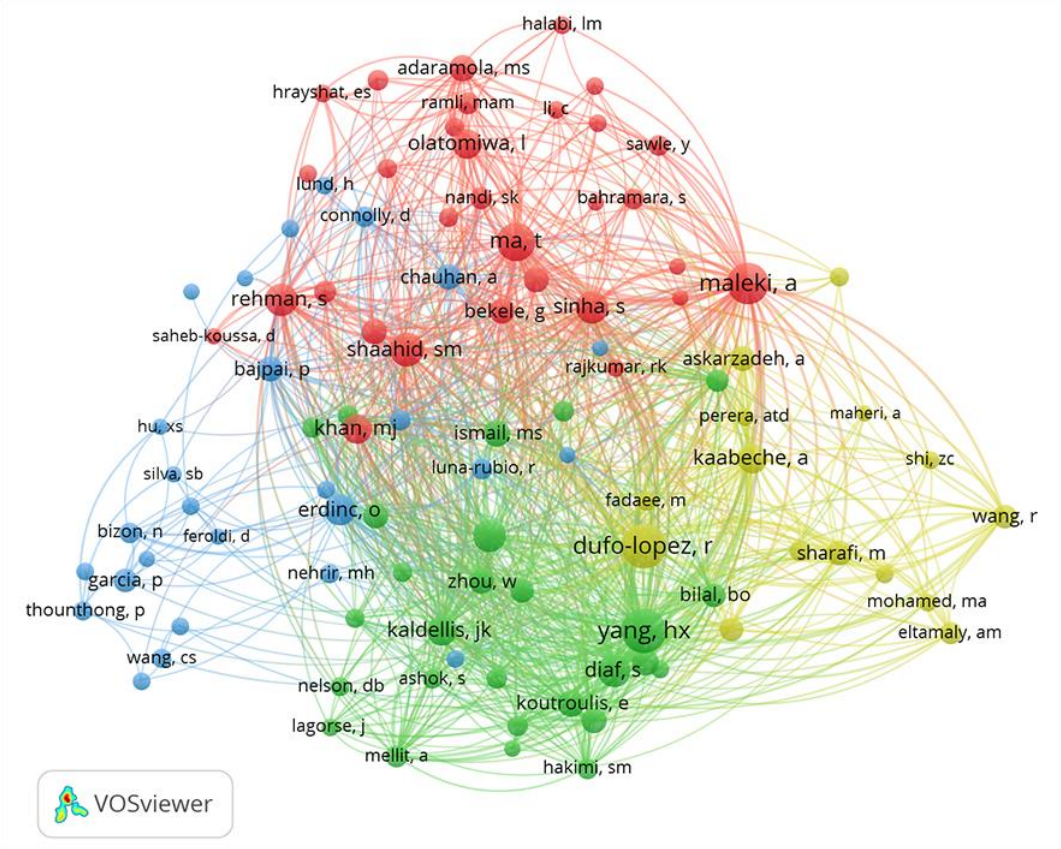

Figure 3. Authors co-citation network

As Figure 6 shows, the co-citation network of authors is distributed in four clusters. The red cluster was the most representative with a total of 31 authors, mainly represented by the group of authors formed by Maleki (120 citations and 2284 total link strength), Ma (108 citations and 1646 total link strength) and Shaahid (82 citations and 1505 total link strength) and the other group of co-authors, including Rehman (79 citations and 1362 total link strength), Shina (77 citations and 1356 total link strength) and Olatomiwa (63 citations and 815 total link strength) link). Using as a reference the studies developed by these researchers, we observed that this cluster mainly concentrates authors who investigate themes related to renewable energy and optimization of the dimensioning and operation of HRES.

The green cluster is composed of 27 authors and has the highest total link strength (23313). The main authors of this cluster are Yang with 140 citations, Bernal-Agustin and Diaf with 78 and 76 citations, respectively. Yang was the author with the highest number of citations and the second with the highest connection strength (2439 the total link strength). Also, Yang has a consistent work with Dufo-López and Kaldellist, with a total of 128 and 76 publications cited together, this can be seen by the thickness of the links. This cluster brings together researchers who show interest in topics related to the control and quality of energy, modeling, and optimization of HRES.

The third cluster (blue) of the co-citations network is formed by 27 authors. The most relevant of them are Erdinc with 72 citations, Bajpai and Chauhan with 49, and 47 citations respectively. The researchers

developed by these authors, taken as a basis for characterizing this group, are predominantly directed to the optimization and control of HRES.

Finally, the yellow set was the smallest with 15 authors, no less important than the other three. This cluster highlights the work of the researcher Dufo-López, who besides being the most cited in the articles sent (145 citations), also appears as the researcher with the greatest total strength of the link (2684), having a co-citation with 96 searches by 100 present in the selection, demonstrating the insertion of his writings in the analyzed field. This researcher is a member of the "Gestión Strategica de la Energia Eléctriaca" research group at the University of Zaragoza, Spain, being one of the first research groups, and perhaps one of the ones with a large number of publications related to multi-objective optimization techniques (based on Genetic Algorithms) for the dimensioning of HRES, in addition to having developed the iHOGA optimization software (Enhanced Hybrid Optimization by Genetics Algorithms), which allows the simulation and optimization of hybrid systems to obtain electricity generation based on renewable energies . In the case of the co-citation relationship between Dufo-López and Bernal-Agustim, it was determined that these were co-cited in a total of 88 publications, in addition to observing the existence of effective collaboration between the authors through co-authorship and because both belong to the same research group.

In general, the great mixture and proximity between the different clusters shows the similarity between the themes researched by the authors. McCain (1990) states that the ACA assumes that researchers, when citing similar and close information sources, address similar research problems in the scientific community to which they belong.

3.2.3 Keywords co-occurrence network

This section presents the co-occurrence analysis of the most used keywords in the titles and abstracts of publications. The analysis was performed using the VOSviewer software. For the elaboration of the keywords co-occurrence network, a minimum number of 10 occurrences was defined, with a total of 79 keywords being selected as shown in Figure 7, these being the ones that determine the central theme of a body of documents.

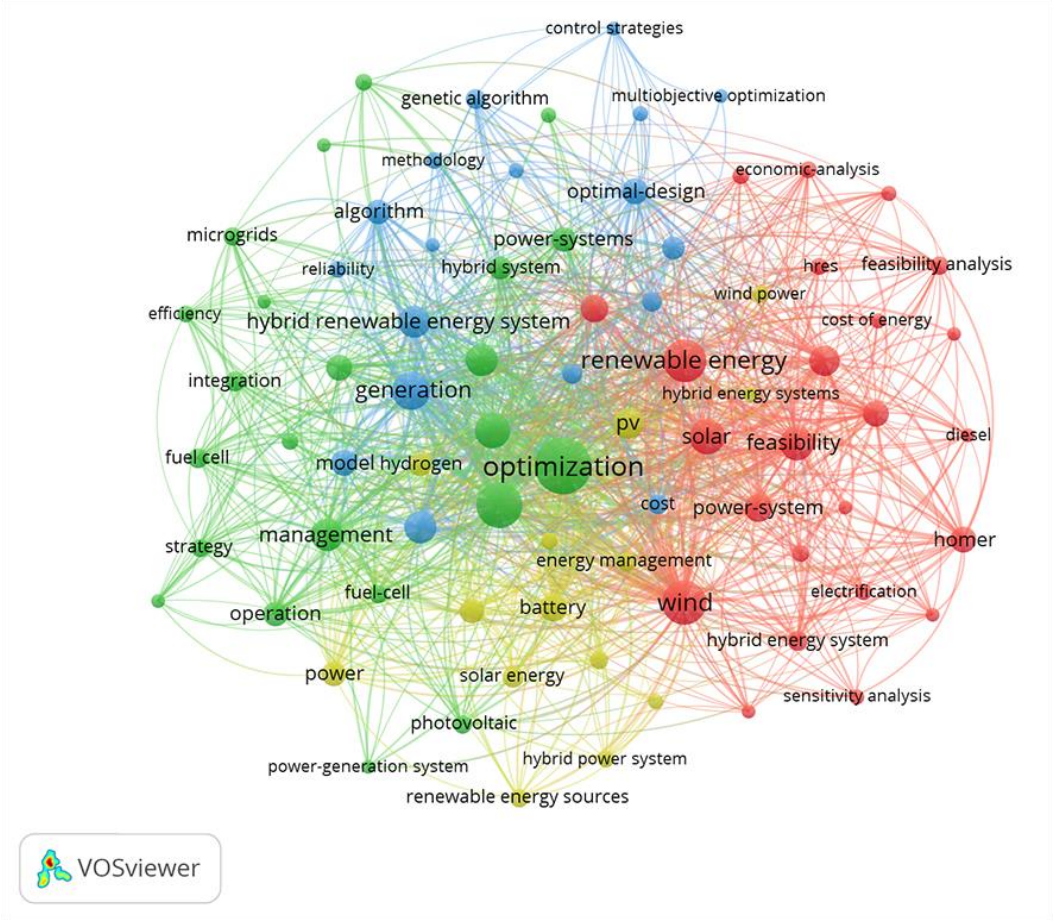

Figure 4. Co-occurrence network of the main keywords

Through Figure 7, the relationship between keywords can be determined. The size of the circles represents the frequency of occurrence of the words, while their proximity indicates the relationship between the research topics, and their relationship is stronger when the distance between them is smaller. The colors are used to distinguish the different clusters (Pauna et al. 2019; Rodrigues et al. 2014; Van Nunen et al. 2018). As shown in the Figure, four main groups of keywords were identified. The yellow subnet is fundamentally concerned with the different energy sources that make up hybrid power generation systems. The blue set focuses mainly on the systems optimization methods and processes. The green group focuses on research related to the characteristics of HRES, while the red group is interested in issues related to economic and financial feasibility analysis.

Table 6 shows the top 10 of the keywords that had the highest occurrence in publications, as well as the total strength of the connections, which are important components of the knowledge structure of scientific production on Optimization of Hybrid Renewable Energy Systems.

Table 6. Top 10 of the most recurring keywords on Optimization of Hybrid Renewable Energy Systems

Keyword	Occurrence	Total strength of the connections
Optimization	152	845
Design	103	567
Wind	96	585
Renewable energy	87	428
Generation	73	402
Storage	63	387
Solar	63	382
Feasibility	56	338
Management	53	312
Performance	53	279

As shown in Table 6 and Figure 7, the keywords with the highest occurrence have their greatest strength in the connections with other words. As expected, the word "optimization" showed the highest occurrence and strength of connection, while the "design" proved to be the second word with the highest level of occurrence followed by "wind". Figure 6 shows that words like "optimization", "design" and "storage" have a strong relationship and this can be seen by the proximity between their nodes. These topics are also becoming increasingly relevant and can be verified by increasing the number of publications since 2010 on these topics.

The 79 keywords are further classified into five categories according to Gao et al. (2016), where the first two categories deal with research subjects related to HRES Optimization, divided into types of energy source (Subject 1) and types of electricity market (Subject 2), the other categories are methods, purposes and research field. This analysis aims to identify the relevant keywords for each category as shown in Figure 8 and to facilitate the study, keywords with the same meaning were considered as one.

In the category of types of energy source (Subject 1), "wind" and "solar" are the most important issues with an appearance percentage of 37,2% and 30,0% respectively. In the category corresponding to types of electricity market (Subject 2) the most representative word was "hybrid renewable energy system" with 36,4% of appearance. The third category referring to methods, the keyword "optimization" was the most relevant with 45,1% of appearance within the category. The use of optimization techniques in the development of hybrid energy systems, enable the productive and efficient use of renewable energy resources. According to Tezer et al. (2017) among the meta-heuristic solutions found in the literature for solving HRES optimization problems, genetic algorithms, evolutionary algorithms and particle swarm optimization algorithms stand out, in addition to the use of the HOMER software used for both simulation and optimization of HRES. Considered the latter as a powerful tool for the design and planning of HRES, in order to determine the ideal size of its components through technical-economic analysis (Bahramara et al. 2016). In general, Figure 8 shows the most popular methods found in the literature related to HRES optimization so that researchers can better identify the most useful ones. In the purpose of the research, the most relevant words were "technoeconomic analysis", "management" and "performance" with percentages of occurrences of 27,3%, 16,0% and 13,6% respectively (see Figure 8).

In the research field category, the most important in terms of occurrence were "design" followed by "renewable energy" and "storage" with the appearance of 24,8%, 20,9% and 15,1% respectively, as shown in Figure 8. The dimensioning HRES is generally done using optimization techniques. These systems, when correctly sized, have a lower cost of generated energy, greater reliability in the supply of energy, in addition to environmental benefits, compared to systems based on a single renewable source (Luna-Rubio et al. 2012). However, the optimal dimensioning of this type of system presents itself as a complex task, which is why it has become a topic of interest to so many researchers, for example (Maheri 2014; Maleki et al. 2016; Wang et al. 2017; Zhang et al. 2013). Several of the works that address the theme of Optimization of Hybrid Renewable Energy Systems consider solar photovoltaic (PV) and wind (WT) generation as the main sources of renewable energy and use batteries as energy storage technology. The use of energy storage resources is taken into account as a complementary component for the optimal design of a HRES, and the integration of this component with sources of solar and wind generation can lead to a flexible and reliable design, whenever the model is well designed for cost effective system operation (Maatallah et al. 2016).

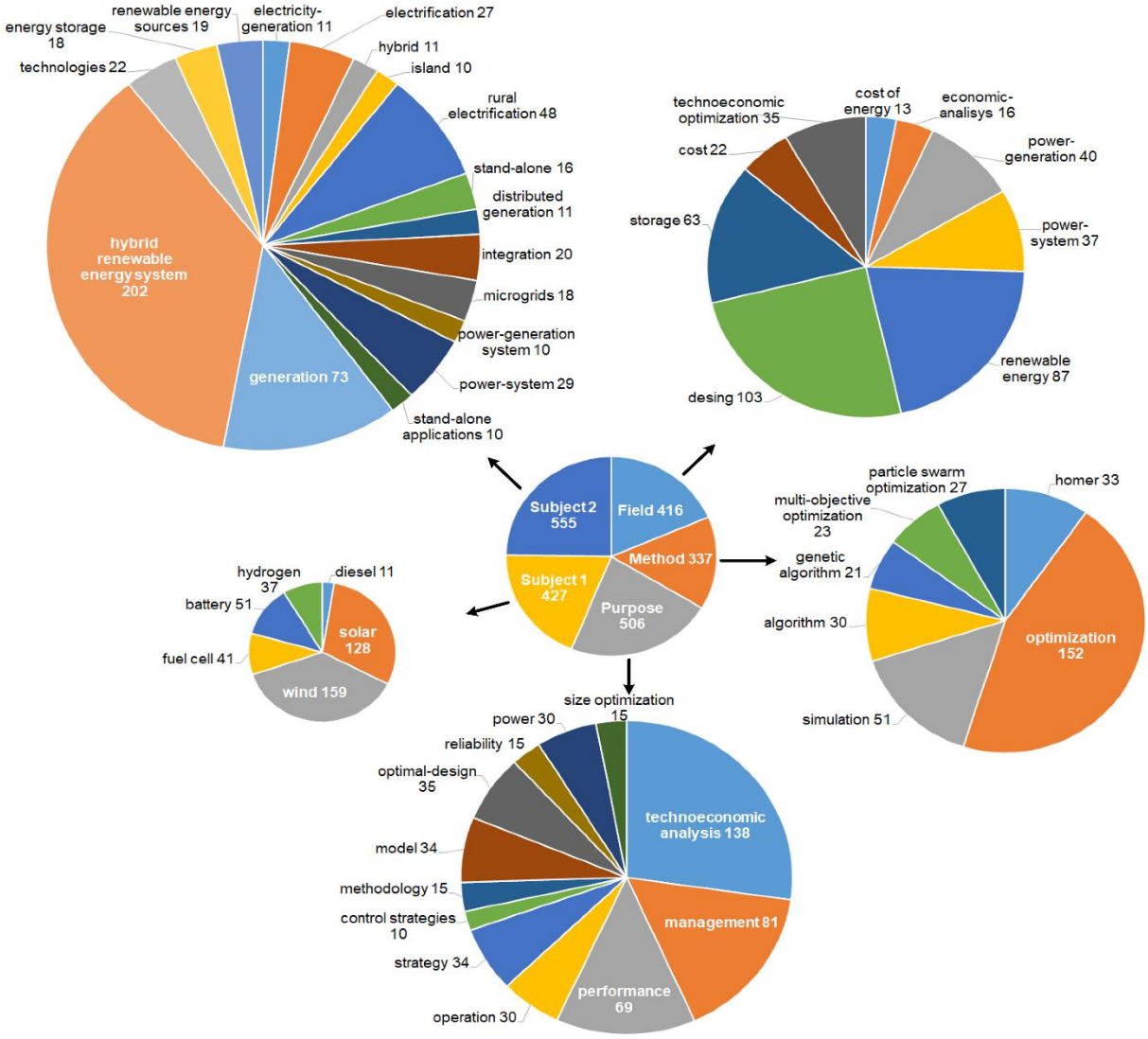

Figure 5. Distribution of keywords by categories

4. Conclusion

This study investigated the evolution of research regarding the Optimization of Hybrid Renewable Energy Systems between the years 2010 and 2020 through bibliometric analysis. Based on the Web of Science database, a total of 439 records related to the topic were obtained. Among them, 389 research articles representing 89% of the total publications. English was the dominant language with 438 records. Publications on the subject have shown a growth profile over the years, which may be related to the development of renewable energies and incentive actions for their greater use. India was the leading country in terms of number of publications with a total of 69 records showing the country's interest in this topic. Among the institutions analysed, University Malaya stands out with the largest number of published papers on the subject with a total of 14.

In the analysis of the publications, it was found that "Energy and Fuel" was the most comprehensive category, which highlights the importance of Optimizing Hybrid Renewable Energy Systems for more efficient generation of energy. The most outstanding authors in a number of scientific productions were Eltamaly Ali, Mekhilef Saad, Olatomiwa Lanre and Jurado Francisco with 7 records each. According to the survey, the articles were published in a total of 123 different journals, indicating that this field has been studied under diverse themes and from various perspectives. The magazines "Renewable Sustainable Energy Reviews" and "Renewable Energy" presented the largest number of publications. The most cited article was "A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configurations, Control, and Applications" published in 2011 and has been cited 351 times, with 35 citations annually.

This study also showed from the science mapping that the United States and the People's Republic of China have played an outstanding role in the cooperation network of the 72 productive countries with 12 connections each, however, it was found that there are still possibilities for development exchange and cooperation in this field. Regarding the analysis of the co-citation network of authors, we can say that most of the authors who are important in terms of citations and total link strength have turned out to be the majority of influential authors in the research field, led by Dufo-López, a researcher at university of Zaragoza Spain having 145 citations and co-citations with 96 researchers from the 100 present in the selection, demonstrating the insertion of his writings in the analyzed field, fundamentally addressing themes related to the optimization techniques for the dimensioning of HRES.

An analysis of the co-occurrence network of keywords revealed that "optimization", "design" and "wind" were the highest co-occurrence index, with a strong link between "optimization", "design" and "storage", which are becoming more and more relevant considering the sufficient range of optimization methods, the existence of variations in technologies and energy systems in HRES, as well as the use of storage resources as a guarantee of greater confidence in these systems. Through the classification of keywords by categories it was found that in the method category, a word "optimization" was the most representative, identifying some of the most popular methods in the literature used to solve HRES optimization problems such as genetic algorithms, algorithms optimization by particle swarm and the use of the HOMER software, enabling the identification and greater use of these by researchers in the area.

The results show the value of bibliometric analysis in the evaluation and quantification of scientific production on Optimization of Hybrid Renewable Energy Systems. In this way, this study provides a useful reference for researchers in the field.

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