Investigating Evolutionary Trends of Hybrid Renewable Energy Systems: A Bibliometric Analysis from 2004 to 2021

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Abstract- Utilization of renewable energy sources is a major topic as energy demands increase and conventional energy sources continue to deplete. Consequently, the quantity of scholarly articles on the topic of hybrid renewable energy systems (HRESs) has increased during the past two decades. This article presents a bibliometric analysis on the topic of HRES using statistical analysis and analysis of publication characteristics to provide a thorough overview of research advancements and trends from 2004 through 2021. The results of a total of 1003 Scopus databases retrieved on February 22, 2022, show that the number of HRES theme publications is increasing year after year. VOSviewer, Rstudio Biblioshiny, Microsoft Excel, and Tableau Public were used to obtain the results of bibliometric analyses of the most prominent authors, number of citations, country productivity, and journals that publish HRES publications. Eltamaly, A.M., is the author with the most publications on this HRES topic, while Maleki, A., has the most citations. India is the most productive country, and Iran is the most cited country in this research theme. Collaboration between countries is also very dominant. In terms of journals, the "Renewable Energy" journal is the primary reference journal for this topic, having the biggest number of publications and h-index relative to other journals. Empirical researchers can use this article to see how study subjects change from year to year and how HRES research themes are changing.

Keywords Hybrid renewable energy systems, bibliometric analysis, research theme.

1. Introduction

The conventional generation of power from fossil fuels is the primary source of greenhouse emissions that can contribute to global warming [1]. Renewable energy sources (RES) such as wind, solar, biomass, and fuel cells can be used to meet future energy needs [1][2]. Solar energy can only be used during the day, and wind energy speeds fluctuate, so studies are beginning to point toward the use of renewable energy sources in a hybrid system. Hybrid renewable energy systems (HRESs) are currently gaining popularity as a means of distributing electricity to rural places [3]–[5], offshore oil mining facility [6], new industrial area [7], and for hospital energy supply [8], [9]. HRESs are commonly used, particularly when network expansion is deemed unaffordable [10]. Hybrid renewable energy systems (HRESs) are a new concept in the world that needs to be researched further. HRESs can provide a solution for a reliable and clean energy supply, especially if fossil fuels become scarce [11]. More attention is placed on developing clean and sustainable energy systems in the design of HRESs. The rapid development of renewable energy technology, the expansion of energy markets, and the adoption of financial strategies and regulations all contribute significantly to the achievement of this objective [12]. The topic of sustainability is primarily evaluated from a technical,

economic, environmental, and social standpoint. There are a variety of interesting subtopics within the field of HRES research, such as decision-making about the combination of renewable energy sources used [13][14], calculation of the costs required for the construction of HRES (net present cost, operating cost, fuel cost) [15][16], environmental impact analysis [15], public acceptance [17], energy management [18] and technology availability [19].

Several review articles have been published by previous researchers to summarize the development of HRESs research on similar topics, such as a review of the energy quality produced by HRESs [20], a review of HRESs mini-grids for electrification of remote areas [21], a review of key perspectives and applications of HRES energy management strategies [22], a review of HRESs sizing methods [23][24], HRESs for water desalination [25], review of the MPPT approach for wind-PV hybrid systems [26], review of trending HRES optimization methods [27], design and analysis of HRESs [28], and HRESs review for railroad electricity [29]. The results include crucial insights regarding designs, methodologies, approaches, and analyses with a greater impact, based on all the reviewed articles that have been referenced. This becomes crucial information for empirical researchers attempting to discover research topics of interest.

Concerning the overall overview of the HRES research map, such as the evolution of trending research topics from year to year, concerns that are becoming hotspots and attracting significant researchers in the HRES theme have not been statistically examined. One approach to gathering this information is through bibliometric analysis [30]. Bibliometric analysis is a quantitative technique for generating a thorough review of the literature [31]. As a result of this, the author wishes to conduct a bibliometric analysis about HRES. This research aims to determine the landscape of HRES publications, beginning with the evolution of the number of publications from year to year, the most prolific authors, an analysis of the number of citations, country productivity, and the journals that publish HRES articles. Furthermore, the writer wishes to demonstrate the research streamlining of this HRESs theme through keyword analysis in order to illustrate the map of thematic evolution and trends. The contribution of this research can provide a statistical evaluation of the development of research publications on the topic of HRES. This article can also provide an overview of the evolution of HRES research topics from year to year. This is useful for determining which topics are outdated, which topics are already in high demand, which topics are developing rapidly, and which topics are rapidly becoming hotspots. Empirical researchers can gain an overview of their future research from these data.

2. Methods

Determining a clear research method is an important step in ensuring that a study achieves its objectives [32]. This research aims to analyze the dynamics, research activities, and trends of research topics related to HREs using bibliometric analysis. Furthermore, the bibliometric analysis data were interpreted to answer the predetermined research questions. Figure 1 depicts the detailed research method.

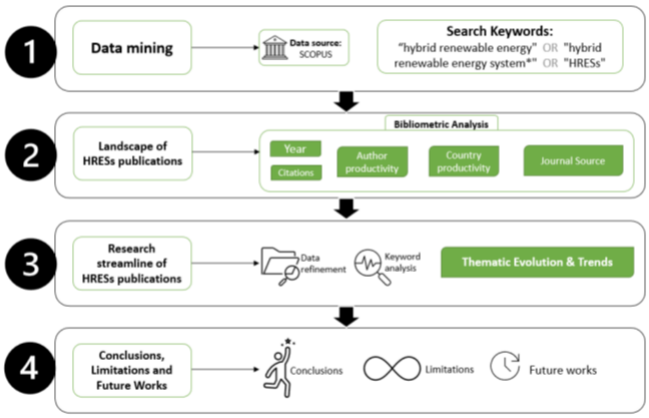


Fig. 1. The research methodology.

The first step, as shown in Figure 1, is data mining. The author's primary data source is the Scopus database. Scopus was chosen because it is one of the largest and most comprehensive indexes of published documents, contains metadata from reputable journals, and supports bibliometric analysis [33][34]. A document search was carried out on February 22, 2022, with the keywords "hybrid renewable energy" OR "hybrid renewable energy system*" OR "HRESs," resulting in a total of 2091 documents. In addition, the authors use inclusion and exclusion criteria to choose the appropriate documents. The inclusion criteria were as follows:

- Document type: article
- Publication stage: final
- Language: English only.
- Source type: journal
- Publication year: 2004 – 2021

The author only uses articles from reputable international journals. Conference papers, reviews, book chapters, conference reviews, books, letters, editorials, data papers, erratums, notes, and undefined publications are excluded. The number of documents used in the research was 1003 after the inclusion and exclusion criteria were applied. The metadata of the 1003 documents is then downloaded in comma-separated value (CSV) format. The second step is to conduct a bibliometric analysis to determine the HRES research landscape. VOSviewer, Rstudio Biblioshiny, Microsoft Excel, and Tableau Public were used for bibliometric analysis in this paper. The factors considered include annual publication trends, citations, author productivity, country productivity, and journals that publish articles on HRESs. Motivated by the analytical strategy of Qin et al. [30], publication trends each year and citations will be analyzed based on the total number of publications (TP), total number of citations (TC), and average citations per publication (AC = TC/TP).

The third step is to identify database keywords and conduct HRES research streamlining analysis. Identification

is accomplished by examining how frequently these keywords are used as well as the relationship between one keyword and another. To reduce bias, we refine the author keywords and index keywords using Open Refine software before using the database in this analysis. The bias refers to keywords with the same meaning that are counted separately. The database that has undergone refinement is then used in the analysis. The results of this research streamlining analysis will be used to determine thematic evolution and the most recent research trends on the topic of HRES. This information will be useful for empirical researchers looking for research gaps and novelties. Based on the data analysis, the final step is to determine research conclusions, limitations, and future work.

3. Results and Discussion

3.1. Landscape of HRESs Publications

3.1.1. Characteristics of HRES Publications

The 1003 Scopus databases used were spread out over the period 2004–2021. In general, Figure 2 depicts the key information from the database.

Fig. 2. Main information from the database.

Figure 2 shows that 1003 documents have been published in 271 international journals. There are a total of 2689 authors, implying that the average number of authors per document is 3.56. HRES theme annual publications account for 37.94 percent of the total. Furthermore, the evolution of HRES theme publications was examined using TP, TC, and AC. The publication progress map is depicted in Figure 3.

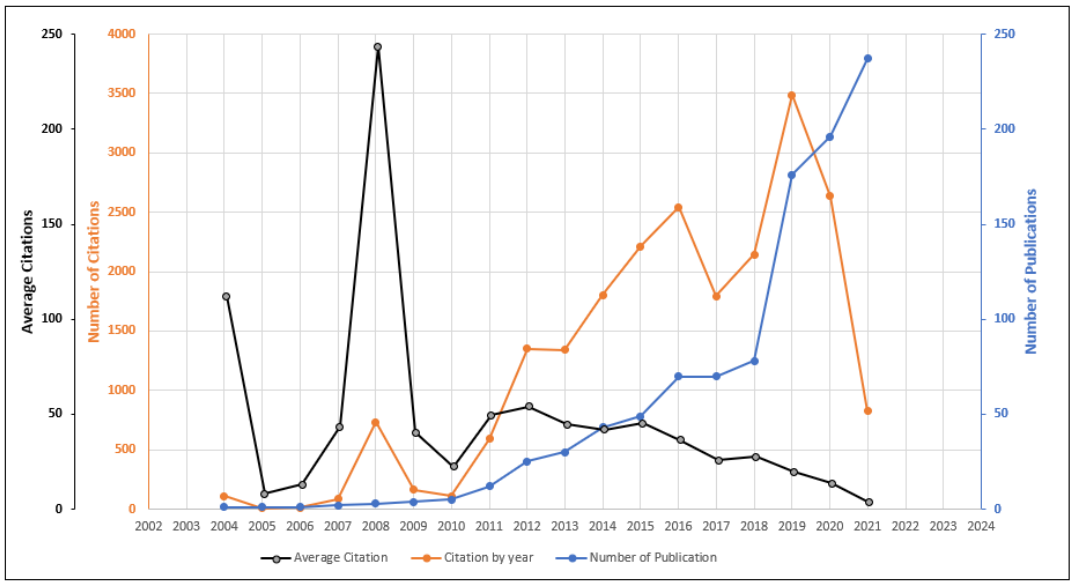


Fig. 3. Trend distribution of TP, TC and AC in HRES publications.

According to Scopus search results from 2004 to 2021, 1003 publications were found using the term "hybrid renewable energy systems." During the period under consideration, the total publication (TP) increased (Figure 3). Data analysis revealed that the growth of HRES-related publications was very slow between 2004 and 2011. Between 2012 and 2018, the number of publications increased by 14.29% per year on average. The number of scientific articles related to HRES has increased significantly between 2019 and 2021, owing to each country's growing desire to build renewable energy power plants as a global consequence of using clean energy and lowering the greenhouse effect. With the increasing innovation of HRESs, there has been a surge in academic interest in the topic; scientific publications on HRESs in 2019 have more than doubled from the results of 2018. This trend is expected to continue until 2021. Because the data is still being updated, the analysis does not include the publication of journal articles in 2022. 609 journal articles were published between 2019 and 2021, implying that publication productivity in the last three years contributed 60.72% of the total for 18 years of HRES research development. This demonstrates that the field of HRES is rapidly evolving, and research into this technology has accelerated in recent years. Unlike the TP, which has an increasing trend every year, the total citation (TC) fluctuates every year. Beginning in 2004, there were 112 citations from 1 document, putting it in second place for AC during the period under consideration. The document is Mohammed and Papadakis [35] which discusses the design, simulation, and economic analysis of a stand-alone reverse osmosis desalination unit powered by two types of renewable energy, namely wind turbines and solar panels. Total citations did not increase significantly between 2004 and 2007. Only in 2008 did the number of citations increase by nearly 8.5 times over the previous year. As a result, the average citation for 2008 is the highest, with 244 citations. Lee and Wang [36] are the authors of the document with the most total citations about HRESs. This document discusses the time-domain stability analysis of an automatic hybrid renewable energy power generation and energy storage system. The number of

citations decreased between 2009 and 2010. The phase of increasing the number of citations occurred consistently between 2011 and 2016, even though the number was the same in 2013. The highest number of citations in a single year occurred in 2019, with 3,487 citations. The highest decrease in the number of citations compared to the previous year's number of citations occurred in 2017, with a total decrease of 29.37%, 2020 with a total decrease of 24.34%, and 2021 with a total decrease of 68.72%. The average citation (AC) has been fluctuating between 2004 and 2012. The highest average citation peaks occurred in 2004 and 2008, with 112 and 244 citations, respectively. There was a downward trend in total average citations from 2013 to 2021.

3.1.2. Characteristics of HRES Publications based on Author Productivity and Number of Citations

An analysis of an author's productivity and number of citations is something that deserves discussion when conducting a research topic analysis [37]. We can easily conduct a document search to learn more about a research topic if we already know which author is the most influential on that topic. According to the database, a total of 2685 authors have published documents on the topic of HRES. Figure 4 depicts the top ten authors on the HRES topic with the most citations, while Figure 5 depicts the top ten authors with the most published documents. The author with the most citations is the most influential on a research topic [38].

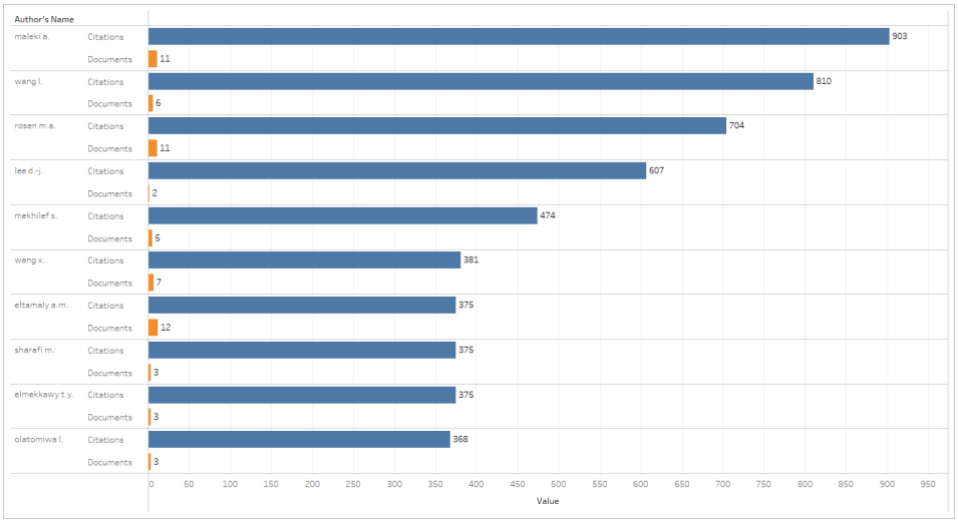


Fig. 4. Top 10 Authors with the highest number of citations.

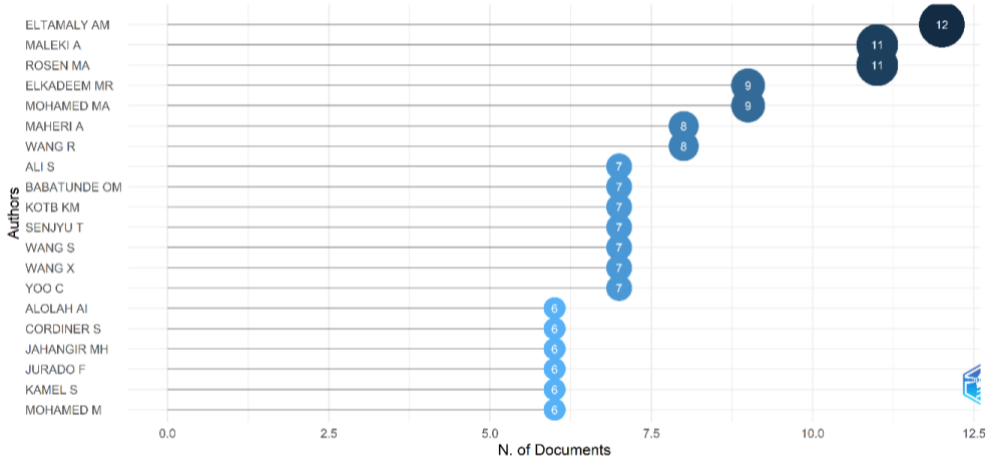


Fig. 5. Top 10 Authors with the highest number of publications.

According to Figure 4, Maleki, A, has the most citations with 903 citations from 11 documents (82 citations per document), making him the most influential author in HRES's research. With 303.5 citations, author Lee D.J. became the author with the highest average citation. That is, even though author Lee D.J. only has two documents, each one receives numerous citations. According to figure 5, Eltamaly, A.M., has the most citations with 12 documents, followed by Maleki, A., and Rosen, M.A., who each have 11 documents.

The total number of citations in the database that we use is 21,963. Table 1 shows the top ten articles with the most citations in the HRES field.

Table 1. Top 10 articles with the highest number of citations.

No	Title	Author(s)	Journal Source / Q	Year	Cited By
1	Small-signal stability analysis of an autonomous hybrid renewable energy power generation/energy storage system part I: Time-domain simulations	Lee D.-J., Wang L.	IEEE Transactions on Energy Conversion / Q1	2008	544
2	Optimal planning and design of a renewable energy based supply system for microgrids	Hafez O., Bhattacharya K.	Renewable Energy / Q1	2012	398
3	Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach	Sharafi M., ELMekkawy T.Y.	Renewable Energy / Q1	2014	263
4	Sizing and Analysis of Renewable Energy and Battery Systems in Residential Microgrids	Atia R., Yamada N.	IEEE Transactions on Smart Grid / Q1	2016	214
5	Operational optimization and demand response of hybrid renewable energy systems	Wang X., Palazoglu A., El-Farra N.H.	Applied Energy / Q1	2015	195
6	Optimization of hybrid renewable energy power systems: A review	Bhandari B., Lee K.-T., Lee G.-Y., Cho Y.-M., Ahn S.-H.	International Journal of Precision Engineering and Manufacturing - Green Technology / Q1	2015	193
7	GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey	Aydin N.Y., Kentel E., Sebnem Duzgun H.	Energy Conversion and Management / Q1	2013	177
8	Performance evaluation of a stand-alone PV-wind-diesel-battery hybrid system feasible for a large resort center in South China Sea, Malaysia	Hossain M., Mekhilef S., Olatomiwa L.	Sustainable Cities and Society / Q1	2017	174
9	Intelligent optimization to integrate a plug-in hybrid electric vehicle smart parking lot with renewable energy resources and enhance grid characteristics	Fazelpour F., Vafaeipour M., Rahbari O., Rosen M.A.	Energy Conversion and Management / Q1	2014	173
10	Techno-economic analysis of a stand-alone hybrid renewable energy system with hydrogen production and storage options	Kalinci Y., Hepbasli A., Dincer I.	International Journal of Hydrogen Energy / Q1	2015	170

According to Table 1, the most cited papers are published in international journals indexed by Scopus Q1. This indicates that publications published in the Q1 journal are the primary reference for the advancement of science, including the HRESs subject. The larger the journal cluster, the greater the difficulty of publishing in it. This pertains to the quality of the research and the articles that were created. Using the database of research publications on HRES topics from 2002 to 2021, the ten articles with the most citations were published between 2008 and 2017, with a total of 2,501 citations (11.38 percent of total citations). Next, we will analyze briefly the primary argument of the 10 articles with the most citations on this HRESS topic.

The first paper with the highest number of citations was published in 2008 by Lee and Wang [36] with a total of 544 citations, making it the earliest article published among the other nine. This article examines the time-domain simulation of the small-signal stability of an autonomous HRE power system and an energy storage system coupled to a load. The proposed renewable energy generation subsystem consists of three wind turbine generators, one diesel engine generator, two fuel cells, and one solar system; its energy storage subsystem is comprised of a battery and a flywheel energy storage system. From the simulation findings, it can be inferred that the proposed hybrid power plant/energy storage system, which supplies an isolated load, can be correctly run to achieve system power-frequency balance.

The second-ranked article with the most citations is Hafez and Bhattacharya's article [39] which received 398 citations. This article discusses the optimal design, planning,

sizing, and operation of hybrid renewable energy-based microgrids with the goal of minimizing life cycle costs while taking environmental emissions into consideration. HOMER software simulates four configurations: diesel-only, fully renewable-based, diesel-renewable mixed, and an external grid-connected microgrid. As a result, a diesel-renewable mixed microgrid configuration has the lowest net present cost (NPC) and emits the least amount of carbon dioxide (CO2) than a diesel-based configuration. Even though the NPC is the highest among the other configurations, a fully renewable-based microgrid configuration is preferred because it produces no carbon emissions.

Sharafi and ELMekkawy [40], which was published in 2014 and had a total of 263 citations, is the article with the third-highest citation count. This article describes the particle swarm optimization multi-objective optimal design simulation of HRESs (PSO). The components of the simulated HRES are wind turbines, PV panels, diesel generators, batteries, fuel cells (FC), electrolyzers, and hydrogen storage tanks, and the findings of these simulations can be used in HRES feasibility studies and designs.

In addition, the fourth-ranked paper with the largest number of citations is Atia and Yamada's [1], which received a total of 214 citations. This article examines the impact of load flexibility on the sizing of residential microgrid components. Optimal component sizing is typically impacted by demand flexibility and is highly reliant on operational conditions.

Wang et al. [41], with a total of 195 citations, is the fifth-ranked paper with the most citations.This article describes a strategy for developing an HRES consisting of solar (photovoltaic), wind, and diesel generators as a backup energy source from present design conditions to more optimal operation. The employed optimization approach is the receding horizon strategy, whose outcomes can achieve global optimization within a certain timeframe while also providing the user with adequate knowledge about future situations. Consequently, users may make reasonable judgments regarding energy and power management.

The sixth-ranked publication with the most citations is Bhandari et al. [42], which was published in 2015 and has 193 citations in total. This article is a review that examines HRESS optimization methodologies applicable to small and isolated power systems. Consequently, through the end of 2014, HRES optimization based on artificial intelligence will remain the leading option.

Aydin et al [43], published in 2013, is the seventh-ranked article with the most citations, with a total of 177 citations. With a case study of western Turkey, this article discusses a GIS-based site selection methodology for HRESs that include wind energy and solar energy (PV). A comprehensive literature review is used to identify environmental acceptability and economic feasibility objectives, and a fuzzy decision-making procedure is used to determine a feasible location.

Furthermore, the eighth-ranked article with the most citations is Hossain et al. [44], which was published in 2017 and has a total of 174 citations, making it the most recent article on this top 10 list. This article examines the performance of a stand-alone PV-wind-diesel-battery hybrid system in Malaysia's South China Sea. The HOMER software is used for economic and technical system analysis. As a result, the best-optimized stand-alone hybrid energy system with PV, wind, diesel generators, converters, and batteries was created.

Fazelpour et al. [45], which was published in 2014 and received 173 citations, is the ninth-ranked article with the most citations. This article discusses intelligent optimization for PHEV smart parking lots (plug-in hybrid electric vehicles). A genetic algorithm (GA) is used for optimization. The results show a decrease in real power losses as well as an increase in the voltage profile through the distribution line.

Kalinci et al. [46], published in 2015, have the tenth most citations. This article examines the technoeconomics of stand-alone HRES that use hydrogen as an energy storage option. HOMER was used to determine the optimal size of equipment based on geographic and meteorological data from Turkey's Bozcaada Island. This study employs two scenarios: wind energy alone and a hybrid of wind and PV. Wind energy and PV hybrid systems have lower NPC than wind turbine systems alone.

3.1.3. Characteristics of HRES Publication by Country

The purpose of this country-by-country analysis of HRES publications is to determine which countries have published the most articles and are the most influential on this topic. Figure 6 depicts the top ten countries with the most HRES topic publications out of a total of 86 countries.

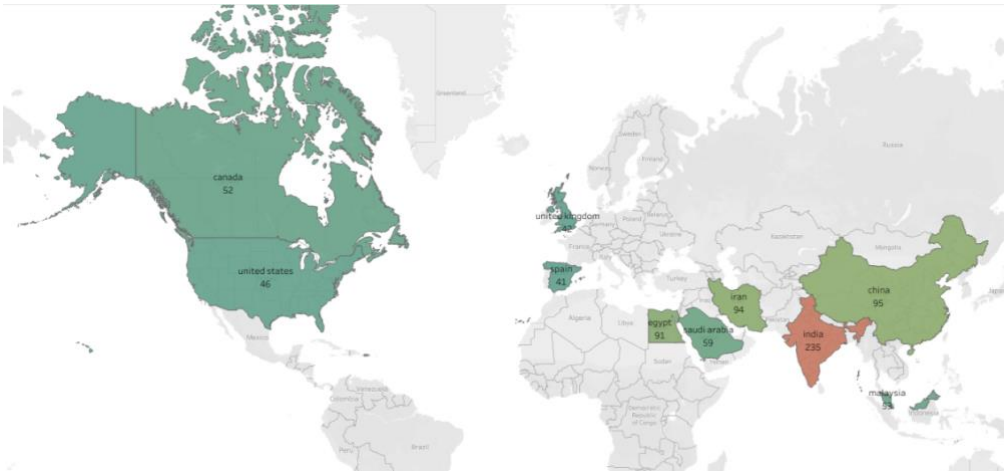
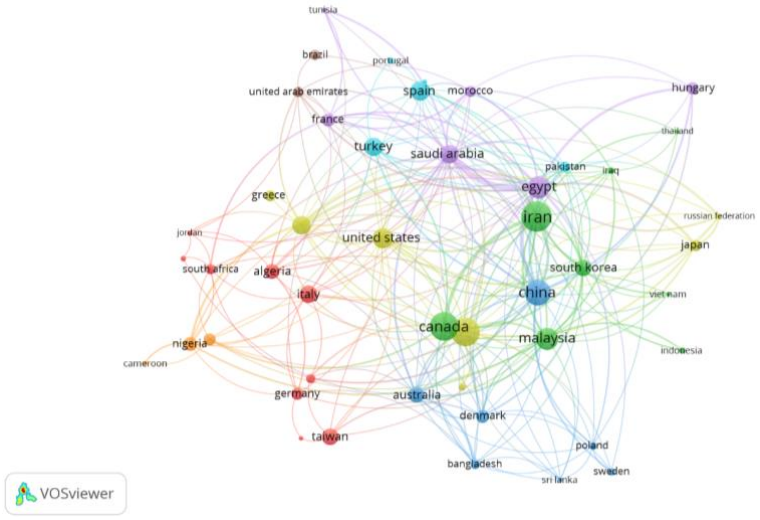


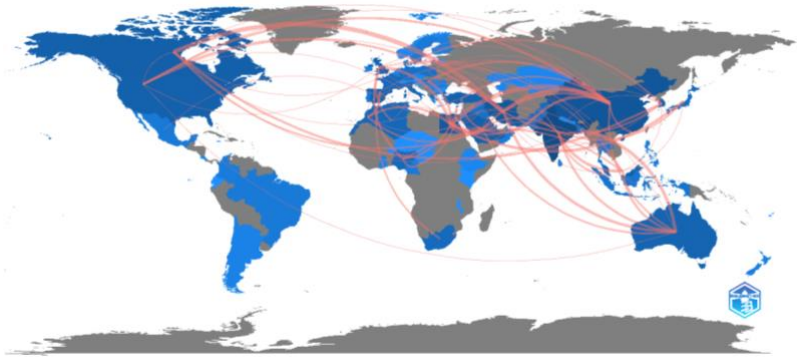
Fig. 6. Top 10 countries with the most publications.

According to Figure 6, India has the most documents (23.43%), with 235 documents. This is noteworthy because, according to several bibliometric studies in the fields of energy and engineering, China and the United States consistently have the highest number of publications [30], [37], [47]. China follows with 95 documents (9.2%), Iran with 94 documents (9.19%), Egypt with 91 documents (9.07%), Saudi Arabia with 59 documents (5.88%), Malaysia with 53 documents (5.13%), Canada with 52 documents (5.03%), the United States with 46 documents (4.45%), the United Kingdom with 42 documents (4.06%), and Spain with 41 documents (3.96%).

Next, we analyze the characteristics of HRES publications based on a map of research collaborations between countries. Fig. 7 shows a map of research collaboration between countries with Vosviewer software and Rstudio Biblioshiny.



(a)



(b)

Fig. 7. Country collaboration in HRES publications.

According to Figure 7, only 48 countries (55.81%) meet the minimum criterion of 5 publications, and 47 countries are conducting research collaborations in the field of HRES. Colombia has five publications but does not collaborate on research with other countries. Each node represents a country's name, and the larger the node, the more citations from that country. Countries' collaborative relationships are represented by connected lines. According to the number of citations, Iran, Canada, and India are the countries with the most citations, with 2927, 2625, and 2578 citations, respectively. The collaboration map shows that author collaboration on HRES topics is active in each country, regardless of continent or geographical location.

Using the SCP (Single Country Papers) and MCP (Multiple Country Publications) criteria, the collaboration map for HRES topic research publications is described in greater detail. Figure 8 depicts the number of publications with SCP and MCP parameters for each country.

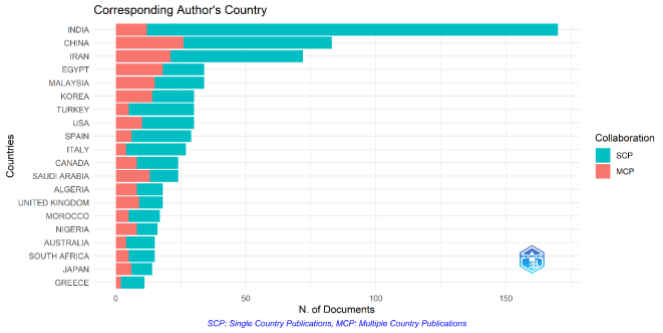


Fig. 8. Number of publications per country using SCP and MCP parameters.

India has the most SCP documents, but China has the most MCP documents, as shown in Figure 8. The conclusion that can be drawn from this data is that Chinese authors work more with authors from other nations than with authors from their own country.

3.1.4. Characteristics of HRES Publications Based on Journal Sources

Several indicators, including h-index, g-index, m-index, quartile, TC (total citations), NP (number of publications), and PY-start (publishing year start), can be used to examine the features of HRES-themed article publications from journal sources [34]. The H-index represents the cumulative impact of an author's, countries, journal's, or institution's scientific output. For instance, if a journal contains 20 articles, each of which has at least 20 citations, its h-index is 20 [48]. The G-index is an alternative to the h-index for measuring publishing output productivity [49]. The M-index is a number that reflects the length of time since the author's or first journal's publication; it is computed by dividing the h-index by the number of years the author or journal has conducted publication activities [50]. The examination of the top 15 journal sources cited in h-index-based HRESS papers is presented in Table 2.

Table 2. Characteristics of journal sources in HRESs-themed publications.

No	Journal Source	h_index	g_index	m_index	Quartile	TC	NP	PY_start
1	Renewable Energy	30	54	1,875	Q1	2929	59	2007
2	Energy Conversion and Management	29	49	2,071	Q1	2522	49	2009
3	Energy	28	46	2,545	Q1	2216	56	2012
4	International Journal of Hydrogen Energy	20	32	1,667	Q1	1182	32	2011
5	Applied Energy	18	25	1,5	Q1	1231	25	2011
6	Journal of Cleaner Production	13	22	1,857	Q1	515	23	2016
7	Solar Energy	13	14	1,444	Q1	951	14	2014
8	International Journal of Renewable Energy Research	12	19	1	Q3	437	34	2011
9	Journal of Renewable and Sustainable Energy	12	17	1	Q3	324	20	2011
10	Energies	11	16	1,1	Q2	389	40	2013
11	IEEE Access	11	18	1,833	Q1	353	20	2017
12	Sustainability (Switzerland)	10	17	1,25	Q2	309	22	2015
13	Sustainable Cities and Society	10	12	1,667	Q1	561	12	2017
14	Sustainable Energy Technologies and Assessments	10	17	1,25	Q1	485	17	2015
15	International Journal of Electrical Power and Energy Systems	9	10	0,818	Q1	575	10	2012

Based on table 2, "Renewable Energy" is a pioneer and superior journal in HRES publications as seen from the majority of parameters, namely the h-index, the g-index, the quartile (Q1), the TC, and the NP. Based on the 2004–2021 range, the journal "Renewable Energy" is also the first journal to publish HRESs articles, namely in 2007, earlier than other journals on this top 15 list. Journals in positions 1–7 are Q1 journals, meaning that when viewed from the quality perspective, journals in quartile 1 have an advantage over other quartile journals when viewed from the h-index. An interesting thing happened in positions 8–10, which were occupied by the journals Q3 (International Journal of

Renewable Energy Research), Q3 (Journal of Renewable and Sustainable Energy), and Q2 (Energy). Judging from PY_start, the two Q3 journals at positions 8 and 9 started publishing HRESs-themed articles in 2011, earlier than the journals at positions 15–20. This must be the cause of this score. Regarding the ranking of this journal's reputation, various factors are considered, including the number of articles, the total number of citations, the number of citations per article, the annual increase in the number of citations, and many more [50].

3.2. Research Streamline of HRES Publications

Author keyword analysis is one of the most important analyses in bibliometric research because it identifies prominent research topics [51]. In this subsection, we will examine the research process for HRES-related publications. Author keyword analysis, thematic evolution, and trending topics are analyzed.

3.2.1. Author's Keyword Analysis

It is important to perform an author keyword analysis to determine the scope and major research themes associated with HRES. There are a total of 2370 author keywords among the 1003 database documents, but only 50 meet the minimum threshold of 10 occurrences. Figure 9 illustrates the author-keyword relationship.

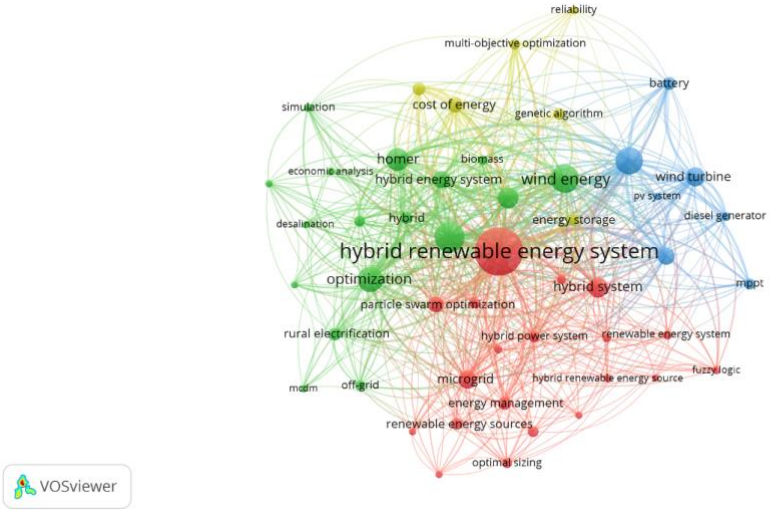


Fig. 9. Visualization of the author keywords network.

Figure 9 categorizes these keywords into four groups. Cluster 1 is displayed in red, Cluster 2 is displayed in green, Cluster 3 is displayed in blue, and Cluster 4 is displayed in yellow. The size of each keyword's node indicates the number of occurrences of that keyword in the database, and the lines connecting each keyword indicate their relationship [52].

Cluster 1 keywords are concerned with HRES as a system. The keyword "hybrid renewable energy system" appears the most, as predicted, with 337 occurrences, 45 relationships with other keywords, and a total link strength of 441. Other terms to consider include "photovoltaic system," "hybrid power system," "hybrid system," "microgrid", and "smart grid." In addition, the keywords "energy management system," "demand side management," "optimal sizing," "techno-economic analysis," "distributed generation," and "particle swarm optimization" are found in Cluster 1. We will begin by discussing the definition of HRES. Energy demands are increasing while fossil energy sources, which are one of the primary energy sources, are depleting [53]. Renewable energy sources such as water, wind, and sunlight can help meet these energy demands. Global warming has a significant impact on the use of renewable energy sources because it causes climate and weather changes, which in turn affect the amount of energy harvested from these renewable energy sources. To meet specific energy needs, such as lighting a remote area, a combination of two or more renewable energy sources is required to obtain optimal energy, or what we can refer to as "hybrid renewable energy systems" (HRESs) [53]–[55]. Ilyas et al [56] review the RESs such as solar, wind and biomass in Pakistan resulting that solar energy is the short term solution to solve the energy crisis.

In terms of energy management systems (EMS), Eyimaya et al [57] used Battery Energy Storage Systems (BESSs) to compensate for energy fluctuations from HRESs that included PV and wind. The designed system is capable of balancing energy production and demand. Another study involving energy management systems involves the use of an evolutionary algorithm capable of controlling charging and discharging even under dynamic load conditions [58]. Furthermore, Kengam et al [59] proposed PSO-CSA (Particle Swarm Optimization-Cuckoo Search Algorithm) to improve power generation performance and meet the stable load requirements of a hybrid renewable energy system (HRES) composed of wind and PV energy. Another EMS strategy is demand-side management [14], [18], [60]. In terms of "microgrid" keywords, there are some interesting studies to discuss. Aljafari et al [61] reviewed the optimization of DC, AC and hybrid Microgrid based on IoT system. The results show that hybrid microgrid has more advantageous compared to DC or AC microgrids. Muleta et

al [62] implement PSO to obtain the most economic and reliable HRES microgrid using MATLAB and HOMER. In case of controlling the voltage instability of microgrid system, PI controller with harmonic filter has an effective results [63]. Esmer et al designed flywheel energy storage that has high efficiency, high speed, and high energy storage capacity to be used in smart grid and microgrid [64]. Besides, Salehpour et al [65] analyzed the realistic failure propagation model for smart grid networks.

The main keyword that appears the most in cluster 2 is "renewable energy," with 142 occurrences, 44 links, and link strengths. Cluster 2 has words like "wind energy," "solar energy," "biomass," "HOMER," "MCDM," and "simulation" that have to do with renewable energy and making decisions. In general, wind energy and solar energy are the most dominant HRES [2], [53], [54], [66]. Meanwhile, the utilization of biomass energy sources (agricultural waste, municipal waste, and animal waste) is combined with solar energy [67] and even combined with solar and wind energy [15][68]. Haque et al identify the efficacy of biogas production from different livestock manures [56]. The results show that goat manure is more suitable for biogas than cattle and pultry manure. About the simulation software, the most commonly used for HRES is HOMER [3], [13]–[15], [54], [55], [68]–[72]. HOMER is an acronym for Hybrid Optimization Model for Electric Renewables, developed by the National Renewable Energy Laboratory in the United States, and is used for the analysis of energy applications, both stand-alone and grid [13]. Other HRES simulation software includes HYBRID 2, SOMES, Energy PLAN, HOGA, RETScreen, and TRNSYS16 [73]. Furthermore, much research on MCDM (multi-criteria decision making) in the field of HRES has been conducted. Ullah et al [74] used MCDM for optimal planning in determining on- and off-grid hybrid systems for energy supply in rural Pakistan, which included solar, wind, hydro, and biomass energy. The criteria considered are economy, dependability, ecology, society, and topography. Ridha et al [69] also conducted a review on multi-objective optimization and multi-criteria decision-making methods for optimal photovoltaic system design. The mathematical model and the output power of the PV panels and batteries are the criteria considered. The findings of the review can provide a general overview of a suitable design for a standalone PV (SAPV) system. Siksnelyte-Butkiene et al [75] conducted a review of MCDM for the evaluation of renewable energy technologies in households. The benefits and drawbacks of the MCDM methods used, such as WSM, AHP, TOPSIS, CRITIC, and EDAS, are also discussed. Diemuodeke et al [13] used MCDM in conjunction with the fuzzy TOPSIS (fuzzy technique for ordering preference by similarity to the ideal solution) method to obtain optimal mapping of HRES locations while taking technical, economic, environmental, and sociocultural factors into account.

Cluster 3's keywords are more focused on "photovoltaic," "wind turbine," "fuel cell," "battery," "diesel generator," and "MPPT." Gajewski and Pienkowski [2] investigated the control of HRESs using wind turbines, photovoltaic panels, and batteries as energy storage in their research related to keywords in cluster 3. The MPPT (maximum power point tracking) algorithm is used to maximize energy conversion from wind and photovoltaic [76]–[78]. The power successfully stored in the battery is then used for load requirements, with the remainder fed to the transformer and fed into the AC grid. Benhadouga et al [79] implemented sliding mode controller to improve MPPT efficiency in solar system resulting the very robust and efficient system. Solis et al analyzed the effect of snow in PV regulator response in a PV park [80]. Furthermore, in the case of fuel cells, Xu et al [81] proposed an optimal structural design for PV and fuel cells based on the Amended Water Strider Algorithm (AWSA) to obtain optimal estimates of the number of photovoltaic panels, electrolyzes, fuel cells, and hydrogen storage tanks in order to obtain the lowest overall net present value (ONPV). Alvarado-M et al did the optimization of single axis discrete solar tracking [82]. The result shows that the energy harvesting is higher than continuous solar tracking.

In cluster 4, costs are the central subject. The search results include the terms "cost of energy", "net present cost", and "reliability." Additionally, this cluster covers "energy storage," "genetic algorithms," and "multi-objective optimization." In techno-economic analysis, the cost of energy (COE) and net present cost (NPC) are closely related. COE is calculated by dividing the entire cost by the amount of energy (kWh), while NPC is calculated by dividing the annual cost by the capital recovery factor [16]. Krishan et al. did a techno-economic analysis on HRES consisting of the ideal wind/battery, PV/battery, and wind/PV/battery combinations to determine the most cost-effective configuration [16]. Consequently, the wind/PV/battery combo is the most cost-effective compared to the alternative configurations that can be implemented in certain places. In addition, the term "reliability" refers to the capacity to provide the load's required power at any moment [83]. Renewable energy cannot be used continuously since it has a finite lifespan. For instance, photovoltaic panels can only collect energy while the sun is shining. That is, the energy storage capacity of the battery, the amount of energy that can be stored and utilized, and the combination with other renewable energy sources to satisfy load needs. Consequently, this characteristic of dependability becomes significant and is accounted for in HRES [72]. Regarding energy storage (batteries), Tharani and Dahiya [84] conducted a simulation to compare the usage of three types of batteries: advanced lead acid (LA), lithium ion (LI), and zinc-bromine (Zn-Br) flow batteries (FB) as energy storage from HRESs utilizing PV-Biogas systems and HOMER software. India's non-electrified village was picked for the case study. Therefore, LI batteries are superior to other battery types in terms of state of charge (SOC), capacity shortfall, and CO2 emission factors. Choosing the appropriate energy storage can be one of the most important aspects of HRES. Moreover, in relation to genetic algorithms and multi-objective optimization, Mayer et al [71] utilized a genetic algorithm to perform environmental and economic multi-objective optimization for household-scale HRES.

3.2.2. Thematic Evolution and Trends of HRESs Research

The following analysis looks at the thematic evolution of the field of HRESs from 2004 to 2021. Figure 10 shows a Sankey Diagram generated with the help of RStudio's Bibliometrix Tools that shows thematic evolution over time.

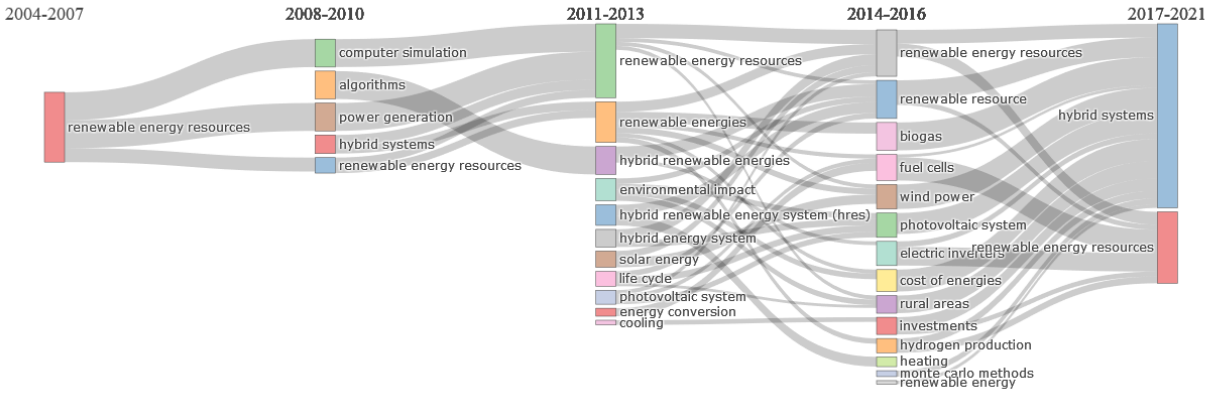


Fig. 10. Thematic Evolution of HRESs research in 2004-2021.

According to Figure 10, each block represents a theme that frequently appears during a specific time. The block's length is proportional to the number of keywords in the theme. The connecting line between the two themes represents the relationship between two themes in different time zones. The closer the two themes are, the thicker the connecting line between them at two different time intervals. When a block in a time range has no connection to the previous time range, it indicates that the theme is new in that year's range. For example, there were eight new themes in the 2011-2013 range that did not exist the previous year, namely environmental impact, hybrid renewable energy systems, hybrid energy systems, solar energy, life cycles, photovoltaic systems, energy conversion, and cooling. This fact led to the discovery that HRESs were first studied as a whole system between 2011 and 2013. Beginning this year, researchers began to investigate the environmental impact of using HRES as an alternative energy source that is more environmentally friendly than conventional energy sources. In the 2014–2016 period, a new theme emerged, namely Monte Carlo methods, which remains related to the big theme of hybrid systems until 2021. Sing et al [85] used a Monte Carlo simulation to assess the reliability of remote HRESs using the loss of load expectation (LOLE) parameter.

In addition, the HRES research trend, which is becoming a focal point, may be determined from the list of author keywords based on the average publication year. Using the VOSviewer program to evaluate co-occurrence keywords, then exporting the data to a.txt file and visualizing it with the Tableau Public 2022 software, the table 3 data for the top 20 keywords is acquired:

Table 3. Research trends and hotspots in HRESs theme.

No	Author Keywords (Theme)	Occurrences	Links	Total Link Strength	Average Publication Year
1	MCDM	10	9	16	2020
2	techno-economic analysis	22	25	51	2020
3	hybrid renewable energy source	13	14	17	2020
4	rural electrification	31	23	73	2020
5	battery	30	22	62	2019
6	Net present cost	31	21	77	2019
7	Optimal sizing	20	17	34	2019
8	Off-grid	18	17	45	2019
9	Energy efficiency	12	14	25	2019
10	Reliability	14	13	17	2019
11	multi-objective optimization	23	20	43	2019
12	Sensitivity analysis	22	22	61	2019
13	Microgrid	56	35	114	2019
14	Biomass	17	23	55	2019
15	Demand response	11	12	17	2019
16	Renewable energy sources	27	18	33	2019
17	PV system	11	15	19	2019
18	Desalination	12	15	26	2019
19	Wind turbine	61	32	131	2019

20	CO2 emission	12	15	29	2019

A keyword might be considered a theme or subtheme of an article based on Table 3. This means that the topics listed above will continue to be popular and important in HRES issues. This information can help academics choose good topics for their research and make sure that those topics are still useful and have not become outdated.

4. Conclusion

In this work, a full bibliometric analysis of the HRESs research theme has been performed for the first time using VOSviewer, Rstudio Biblioshiny, Microsoft Excel, and Tableau Public. The chosen database is Scopus. The analysis focuses on the development of the number of publications from year to year, the most prolific authors, an analysis of the number of citations, country productivity, and collaborations, journals that publish HRES articles, and the thematic evolution of these HRES topics from 2004 to 2021.

From 2004 to 2022, the number of HRES articles published in international journals increased on an annual basis. Nevertheless, the total and average number of citations fluctuate annually. A.M. Eltamaly is the author with the most publications on this HRES topic. While Maleki, A., has the largest number of citations, also the author with the second-highest number of publications. It turns out that there is no relationship between the number of publications and the number of citations. This article also identified the top ten articles with the most citations, with the work by Lee D.-J. and Wang L. receiving the most citations in IEEE-Transactions on Energy Conversion. China, Iran, and Egypt hold the top three positions in terms of the highest number of publications on HRESs topics, each with a somewhat different number of works. From the map of author collaboration between countries, it can be seen that China collaborates the most with other countries. In addition, the Renewable Energy magazine has the most publications and the highest h-index for HRESS-themed articles. This bibliometric study also uncovered a link between author keywords that demonstrates the evolution of subtopics within the HRES theme. As a result, there are twenty topics that are trending and can provide an overview of topics for empirical researchers, including "MCDM", "techno-economic analysis", "hybrid renewable energy sources", "rural electrification", "battery", "Net present cost", "Optimal sizing", "Off-grid", "Energy efficiency", "Reliability", "multi-objective optimization", "Sensitivity analysis", and "Microgrid".

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