Research trend on the effects of COVID-19 on renewable energy

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ABSTRACT

The number of studies on COVID-19 has rapidly grown in recent years. The pandemic has caused widespread disruption, including in renewable energy research. This study aims to examine the impact of the COVID-19 pandemic on renewable energy research by conducting a bibliometric analysis from the Scopus indexing database from 2020 to 2023. This study employs a bibliometric approach to analyze the authors, affiliation, publication source, keywords, thematic map, and trend topic. The analysis will focus on the comprehensive overview of the published research and identify areas where future research is needed. The results show that the number of research studies related to COVID-19's effect on renewable energy will continue growing and a solid collaboration network exists. China has had a significant presence on the impact of COVID-19 on renewable energy studies, including organization and university affiliations, number of single and multiple country publications, funding sponsors, and most cited countries. The finding also shows niche themes, research trends, and thematic evolution shifting. This finding will contribute to a better understanding of the impact of the COVID-19 pandemic on renewable energy research and a new direction for future research.

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1. INTRODUCTION

The first concern of the World Health Organization (WHO) regarding COVID-19 was the outbreak of a novel respiratory illness in Wuhan, a city of Hubei province, People's Republic of China (PRC), in December 2019 when Chinese authorities reported a cluster of cases of pneumonia with an unknown cause [1]. Governments and health organizations have implemented travel bans and lockdowns to slow the spread of the virus. This condition significantly impacts the world in many worldwide aspects. A study from [2] shows that the pandemic has overwhelmed healthcare systems in many countries and frontline workers have been put under post-traumatic stress symptoms. The pandemic has caused widespread socio-economic disruption, with businesses shutting down, disrupted supply chains, and millions of people losing their jobs [3]. Governments worldwide have implemented economic stimulus packages to support workers and businesses who lost jobs and output [4]. In the education sector, the pandemic has disrupted educational systems worldwide, with schools and universities forced to blended online learning [5]. Another study from [6] finds that the pandemic has significantly impacted mental health, with people experiencing anxiety and depression due to lockdown conditions. The pandemic affected social life, especially for students, with restrictions on gatherings and events impacting mental health and well-being [7]. Under such occurrences, the electricity sector is also profoundly affected and faced with significant challenges [8], [9].

The global COVID-19 pandemic has exerted profound and far-reaching impacts across various sectors, reshaping the dynamics of economies and societies worldwide. A study from [10] examines the changes in electricity demand, in which many people working from home and businesses closed or operated at reduced capacity, causing drastic changes in load profile. The residential consumer has increased, while commercial and industrial demand has decreased. The load behavior change has led to changes in how the electrical power system is planned and operated [11]. This condition may increase the risk of power outages and other infrastructure failures because of an unexpected shutdown when some power plants cannot produce electrical energy [12]. A study from [13] elaborates on the importance of power system resilience in ensuring that critical infrastructure can withstand high-impact low probability events. The pandemic also affected delays in deploying renewable energy projects as part of the energy transition due to disruptions in supply chains and construction activities [14].

The global push towards a sustainable future has catalyzed a significant energy transition, with an increasing focus on harnessing renewable sources. The energy transition is directed to shifting from using conventional energy sources (such as fossil fuels) to new and renewable with low-carbon energy sources (i.e., hydro, biomass, geothermal, hydrogen, solar, wind, and ocean energy) to mitigate climate change and reduce greenhouse gas emissions [15]. The energy transition is driven by the need to reduce the environmental impact of energy production and use and improve the utilization and performance of renewable energy technologies [16]. This transition aligns with environmental goals and fosters energy security and independence. This shifting involves changes in how energy is produced, distributed, and consumed. Various factors influence the energy transition, including technological advancements [17], policy frameworks [18], public preferences [19], and market dynamics [20]. As the world collectively works towards a low-carbon future, integrating renewable energy technologies stands at the forefront, driving a paradigm shift in the global energy mix.

Renewable energy penetration faces several challenges. A study [21] shows that variable renewable energy sources such as solar and wind have intermittent characteristics, meaning the sources are not steady depending on nature's condition. This condition can create challenges for grid operators in balancing supply and demand and requires energy storage or flexibility with high ramp rates to ensure a reliable electricity supply [22]. From a financial point of view, although renewable energy technologies have decreased significantly in recent years [23], they still require substantial upfront investment, particularly in the case of large-scale projects [24]. The cost of renewable energy must be competitive with existing conventional energy sources to drive widespread adoption. Deploying renewable energy sources also requires high investment in electrical grid infrastructure, including transmission and distribution lines [25]. In some cases, there may be limited availability of suitable land for large-scale renewable energy projects, particularly in densely populated areas. In some areas, renewable energy is suitable for underdeveloped, frontmost, and outermost regions, mainly for archipelago countries [26]. The researchers [27] investigation shows that government policies and regulations can significantly impact the deployment of renewable energy. Political and regulatory uncertainty can create risks for investors and delay the deployment of renewable energy projects. Another study shows that public support for renewable energy is generally high [28]. Local opposition to specific projects may exist due to concerns over land use, visual impact, or noise pollution [29]. Moreover, renewable energy technologies have made significant progress in recent years, and technological limitations still need to be addressed [30]. Energy storage technologies must become more efficient and cost-effective [31], allowing for greater penetration of intermittent renewable energy sources into the grid [32].

Bibliometric research is a quantitative analysis method that explores scholarly publications and their citation patterns. It is a statistical analysis of bibliographic data that can measure various aspects of scientific research, such as the productivity and impact of authors and institutions, the intellectual structure of a field, and the relationships between different fields and subfields [33]. This approach systematically analyzes bibliographic data, such as publications, citations, and collaboration patterns, to gain insights into the structure and dynamics of scholarly communication. Some researchers investigated renewable energy with the bibliometric method, i.e., artificial intelligence in renewable energy [34], 100% renewable energy system [35], the different types of renewable energy finance [36], renewable energy types using key performance indicators with multicriteria decision models [37], and many more.

Although many articles and reviews have been published on renewable energy, the need for bibliometric analysis concerning the effect of COVID-19 must be determined. Based on a Scopus-indexed database, the review employs analysis including documents, authors, affiliations, publication sources, words, keywords, thematic map, and tren topic. The manuscript is structured as follows. The materials and method, including bibliometrix tools and search criteria, are all defined in section 2. Simulation results are all covered in section 3. Section 4 is the discussion section, while section 5 is the conclusion and future research.

2. MATERIALS AND METHODS
2.1. Bibliometric analysis
Bibliometric analysis is a quantitative method employed to systematically assess and analyze the characteristics of scholarly literature within a particular field or discipline. This analytical approach involves examining bibliographic data, including publications, citations, and collaboration patterns, to extract meaningful insights and quantify various aspects of academic research. Researchers and institutions utilize bibliometric analysis to evaluate the impact and influence of scholarly works, identify key contributors and research groups, and track the evolution of research trends over time. By employing statistical and computational techniques, bibliometric analysis enables the measurement of publication output, citation impact, and collaborative networks. This method plays a crucial role in mapping the intellectual structure of a field, highlighting influential works, and identifying emerging research areas. Bibliometric analyses are conducted using specialized databases and software, allowing researchers to understand the scholarly landscape comprehensively, make informed decisions about collaborations, and contribute to evidence-based research assessments. Many software tools enable bibliometric analysis (i.e., VOSviewer [38], CitNetExplorer [39], BibExcel [36], [40], science mapping analysis software tool (SciMAT) [41], Science of Science Tool [42], VantagePoint [43], and CiteSpace [44]); nevertheless, many do not help researchers in a comprehensive recommended workflow. Bibliometrix is a comprehensive R package for performing bibliometric analyses, which involves the analysis of scholarly publications and their citation patterns. Bibliometrix provides various tools for importing, cleaning, and analyzing bibliometric data, including co-authorship, co-citation, and bibliographic coupling analyses. Bibliometrix supports multiple bibliometric analyses, including co-occurrence, bibliographic coupling, and citation analysis [45].

2.2. Search criteria
Scopus integrated citation and abstract databases with supplemented data across. This study uses the Scopus indexing databases to collect a dataset. Scopus integrated citation and abstract databases with supplemented data across various fields, i.e., energy, engineering, environmental science, mathematics, computer science, multidisciplinary, and many more. This indexing database quickly identifies experts' authoritative and relevant research and provides access to analytical tools with metrics. This study uses the Scopus indexing databases to collect a dataset. Scopus integrated citation and abstract databases with supplemented data across various fields, i.e., energy, engineering, environmental science, mathematics, computer science, multidisciplinary, and many more. This indexing database quickly identifies experts' authoritative and relevant research and provides access to analytical tools with metrics. On the Scopus website, we use article titles, abstracts, and keywords in search within the query column. We use "COVID AND Renewable Energy" in the search document query. The AND operator in Boolean logic is a logical operator that takes two Boolean values and returns true only if both keywords are true. This operator is used to combine multiple search criteria or conditions.

3. RESULTS
3.1. Main information
Research document annual production refers to the number of publications produced by researchers, institutions, or countries in a given year. The documents can refer to journal articles and conference proceedings. Measuring the annual production of research documents is a meaningful way to track the researcher's productivity in the COVID-19 and renewable energy research. The yearly scientific output in the BIPV research field is shown in Figure 1. The annual growth rate is 15.09%, indicating that the COVID-19 and renewable energy research field is growing and attracting significant research production. The average citation is 11.54 per document. Figure 2 shows the top ten most globally cited documents. The research entitled Sustainability and Development after COVID-19 by EB Barbier is the most cited document investigating the highly vulnerable developing countries to the COVID-19 pandemic for securing progress towards sustainable development goals (SDGs) [46].

3.2. Authors
Bibliometric analysis often involves analyzing authorship patterns, such as the number of publications produced by a particular author or research group and the collaborations among authors. This information can provide insights into the productivity and impact of individual researchers and the networks of collaboration within and across research fields. Jiří Jaromíris Klemeš from Brno University of Technology, Brno, Czech Republic, is the most relevant author on the COVID-19 effect on renewable energy research with seven documents. The top ten relevant authors from a total of 2,631 are shown entirely in Figure 3.

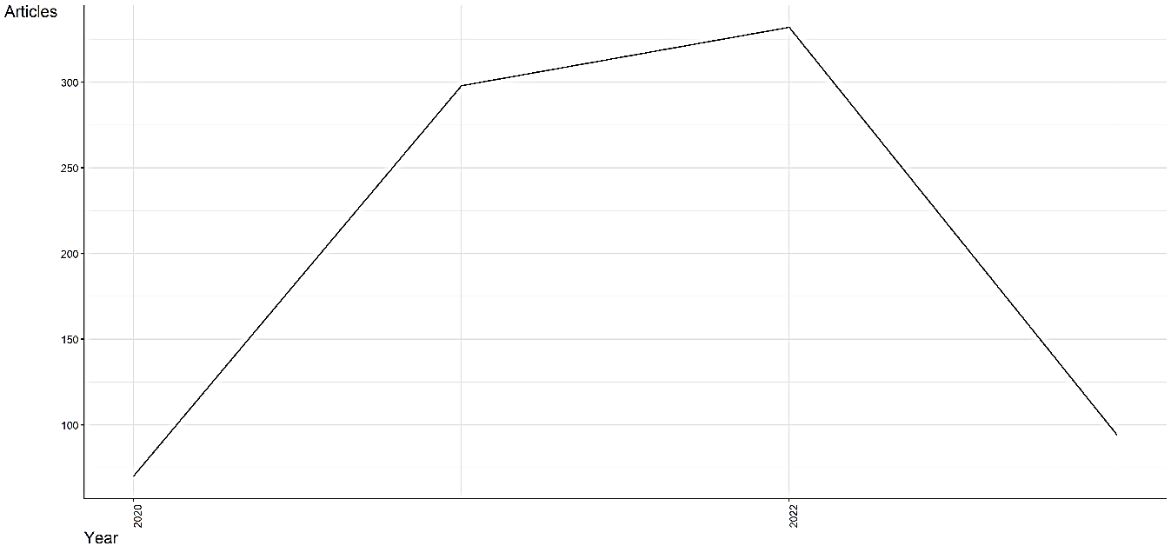

Figure 1. Annual research productivity

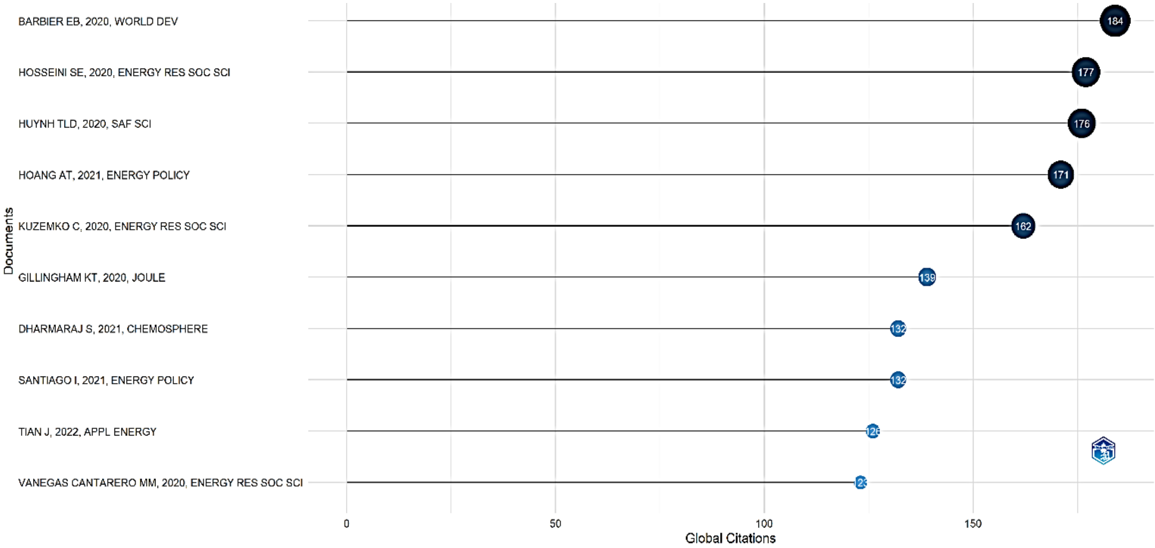

Figure 2. Most globally cited documents

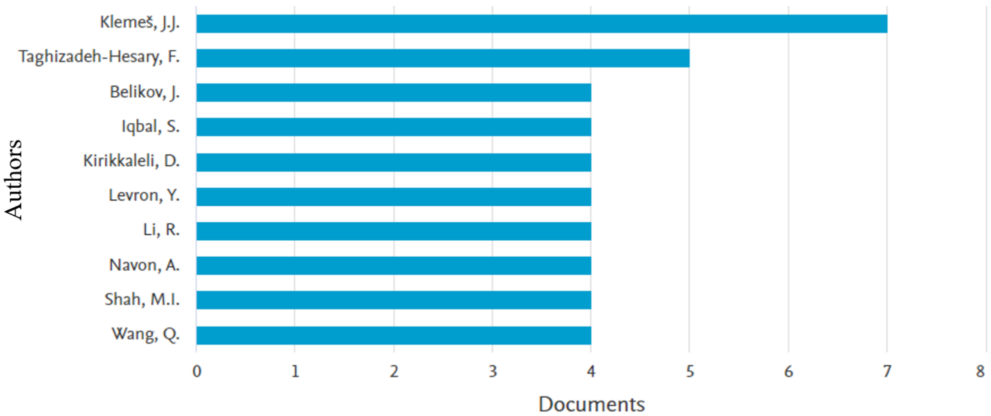

Figure 3. Most relevant authors

The h-index is a metric that measures both the productivity and impact of a researcher's publications. This metric is calculated based on the number of publications a researcher has published and the number of times other researchers have cited those publications. Jiří Jaromíris Klemeš, with an h-index of 6, has published six papers that have each been cited at least six times. It means the researcher has both the quantity and impact of a researcher's work. The top five authors with the highest impact by h-index are shown in Figure 4.

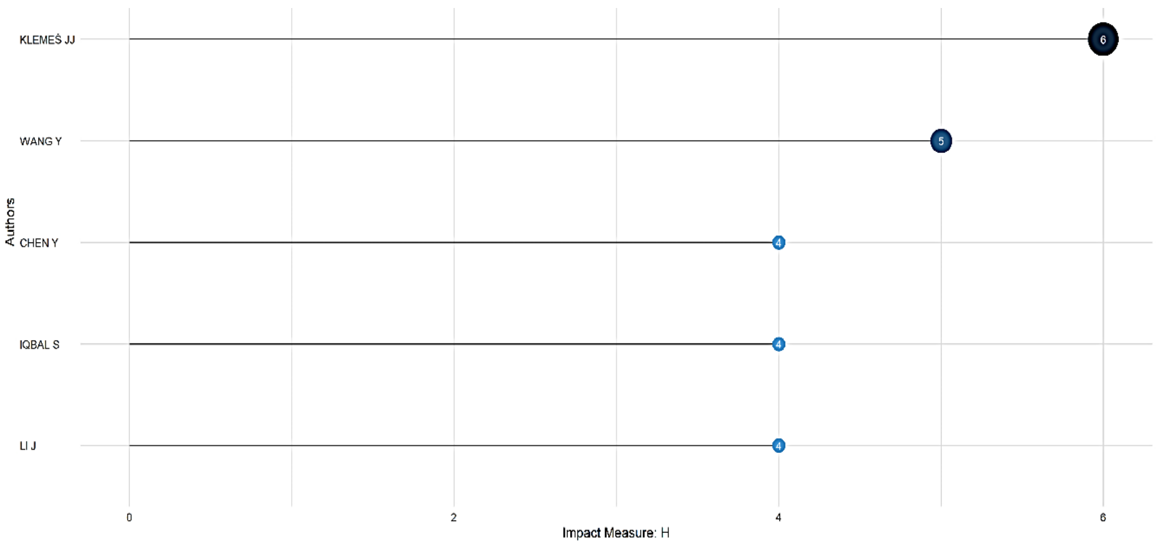

Figure 4. Authors impact by h-index

In author analysis, a collaboration network guides the collaborative relationships between authors based on their co-authorship of publications. The networks inform the patterns of collaboration among researchers and the structure of scientific communities. The co-authors are 3.79 per document. Each node represents an author, and each edge represents a co-authorship relationship. Collaboration networks can also be used to identify potential collaborators or evaluate the impact of collaborative research projects. Figure 5 shows one solid collaboration pattern among four research groups (red, green, blue, and purple).

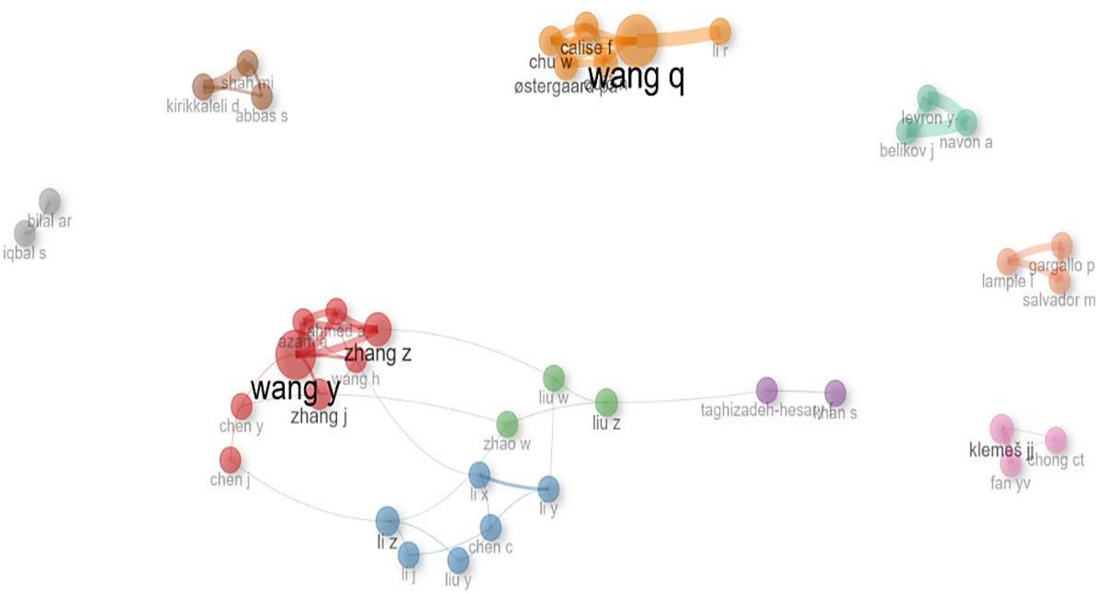

Figure 5. Collaboration network

3.3. Affiliations

Affiliation analysis refers to the organization or institution an author is affiliated with, such as a university or research center. Each publication indexed in Scopus is associated with one or more author affiliations, which can be used to analyze patterns of research output and collaboration at specific institutions, especially in the effect of COVID-19 on renewable energy studies. This analysis can be helpful for various purposes, such as identifying key universities or research centers or evaluating the impact of collaborations between countries. Table 1 shows the most relevant affiliation in the effect of COVID-19 on renewable energy research. Shanghai Jiao Tong University has the highest affiliation production with nine documents. Another affiliation from China, the Beijing Institute of Technology, is in the top ten affiliations. China has had a significant presence in COVID-19 research, with researchers from Chinese institutions contributing to many publications. According to bibliometric analysis of COVID-19 publications, Chinese authors accounted for a substantial proportion of COVID-19 research output, particularly in the early stages of the pandemic [47], [48]. Figure 6 confirms that China is the dominant country in researching the effect of COVID-19 on renewable energy.

Table 1. Documents by affiliation

Affiliation	Results
Shanghai Jiao Tong University	9
Imperial College London	8
European Commission Joint Research Centre	8
University of Economics Ho Chi Minh City	8
University of Johannesburg	7
Zhejiang University	7
Brno University of Technology	7
Beijing Institute of Technology	7
Aalborg University	7
UNSW Sydney	7

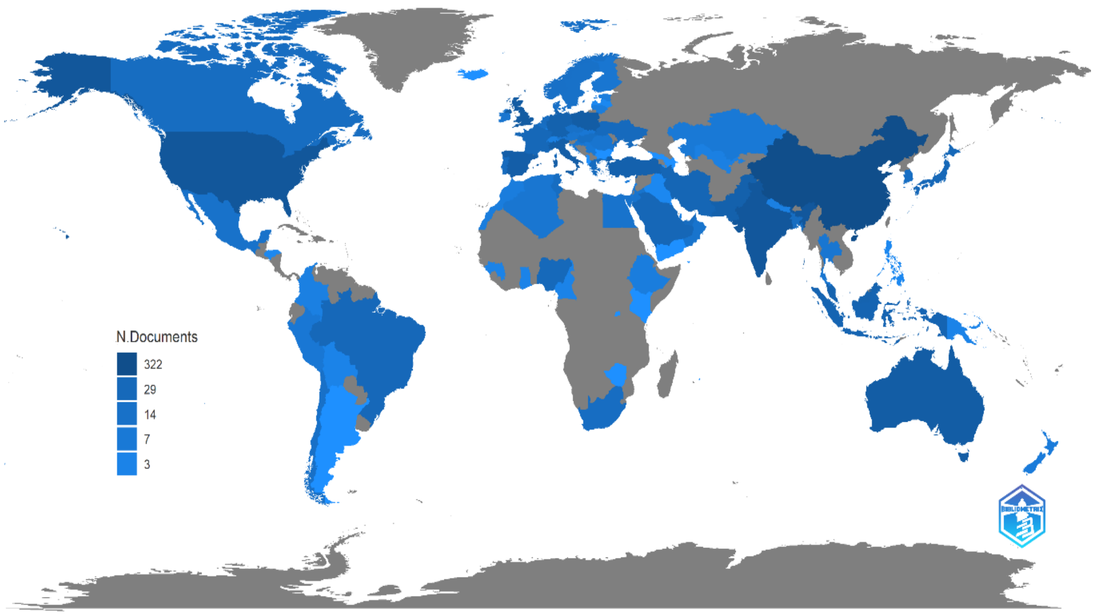

Figure 6. Countries scientific production

Figure 7 shows the corresponding author's country. Researchers from only one country authored a single-country publication (SCP). SCP means that all publication authors are affiliated with institutions in the same region. On the other hand, a multiple-country publication (MCP) refers to a research publication by researchers from two or more countries author. MCP means that the publication's authors are affiliated with institutions in different countries. This analysis can provide insights into patterns of international collaboration in this research field. China's high proportion of MCPs suggests a high level of collaboration and knowledge exchange between researchers from different countries. The dynamic country production in 2020 to 2023 in Figure 8 indicates that China is the most productive country that consents to the effect of COVID-19 on renewable energy.

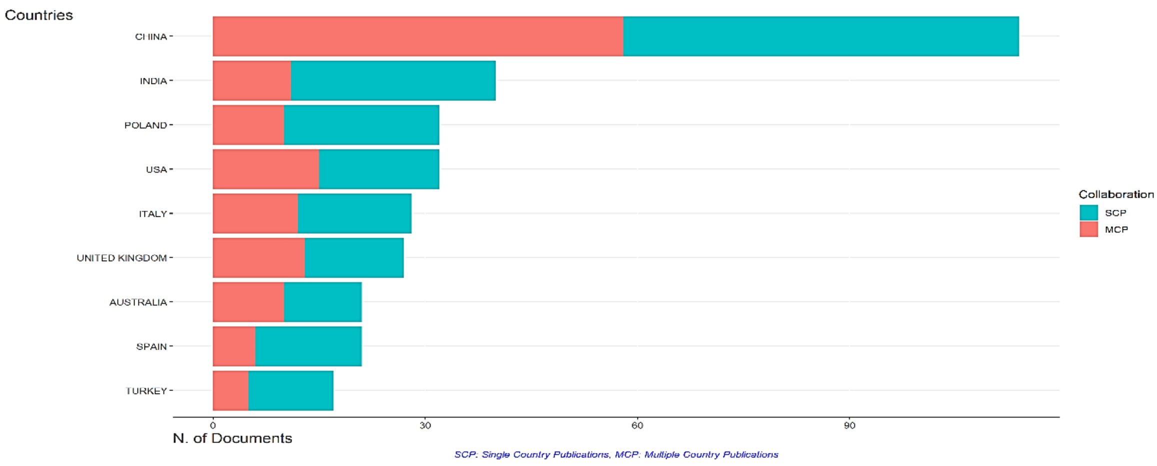

Figure 7. Corresponding author's countries

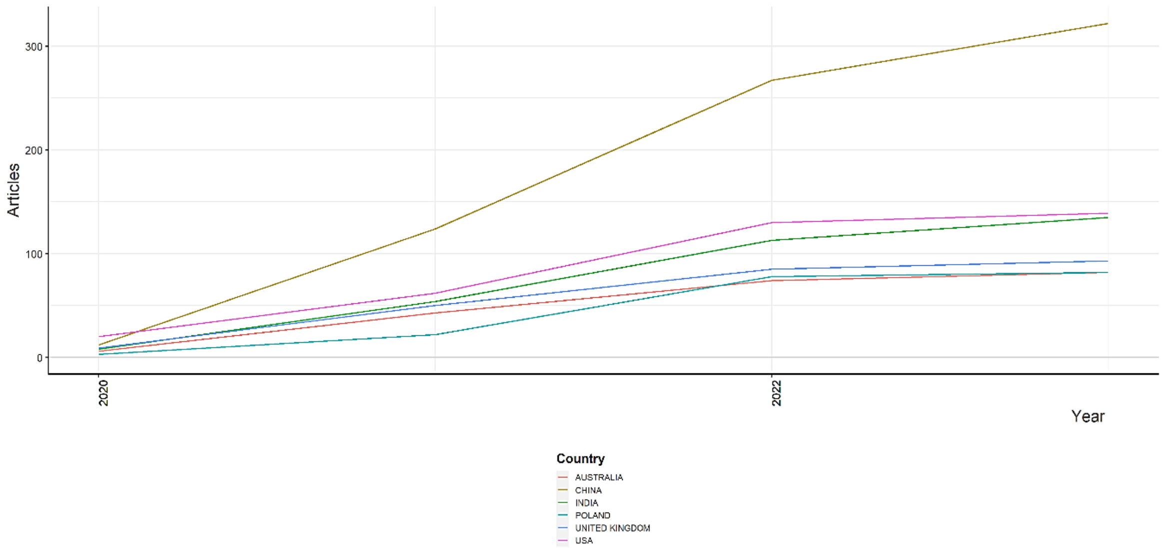

Figure 8. Country production over time

Despite the high number of publications from China, this country has provided substantial funding to support research on COVID-19 domestically and internationally. Some significant funding sponsors of COVID-19 research in China include the National Natural Science Foundation of China and the National Key Research and Development Program of China, as shown in Table 2. With high productivity and significant funding sponsors, China is the most relevant country as a reference for the effect of COVID-19 on renewable energy research, as shown in Figure 9.

Table 2. Documents by funding sponsor

Funding sponsor	Results
National Natural Science Foundation of China	51
European Commission	23
Fundamental Research Funds for the Central Universities	11
National Office for Philosophy and Social Sciences	11
National Key Research and Development Program of China	10
Horizon 2020 Framework Programme	9
European Regional Development Fund	8
National Science Foundation	8
Engineering and Physical Sciences Research Council	7
Fundação para a Ciência e a Tecnologia	7

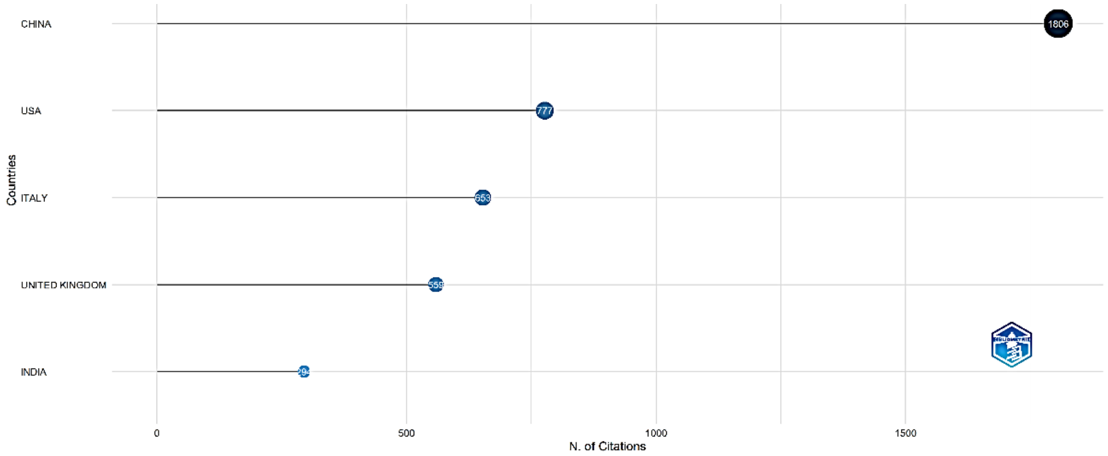

Figure 9. Most cited countries

3.4. Publications

The source refers to the analyzed publication, such as articles, books, conference papers, reviews, data papers, editorials, letters, notes, and short surveys. This study identified and indexed in bibliographic databases from the Scopus indexing database. The analysis can provide insights into trends in scholarly publishing on the effect of COVID-19 on renewable energy research, such as the most influential journals, publication yearly dynamics, core sources, and the most frequently cited journals. This information can be helpful for researchers, policymakers, and funding agencies interested in tracking the progress and identifying areas where further research is needed. Figures 10 and 11 show that Energies are the most relevant Journal every year on the effect of COVID-19 on renewable energy research with 68 documents.

The h-index is intended to provide a more nuanced measure of source impact than simple measures such as the number of publications or total citation count. By considering the quantity and quality of a researcher's work, the h-index can provide a more balanced and reliable measure of a researcher's scientific impact. Figure 12 shows that Energies Journal has a high impact, with 15 of the h-index.

Bradford's law is a principle that suggests that the literature of a particular field can be collected into a core source. These are the most highly cited and influential publications in the field. The core source suggests that a small number of highly cited publications or journals are responsible for a large percentage of the citations on the effect of COVID-19 on the renewable energy field. This group can be represented by a steep slope in the Bradford plot, with the core zone of highly cited publications appearing at the leftmost part of the plot. Figure 13 shows there are 14 sources classified as core sources. The core sources can help researchers and professionals better navigate the complex landscape of scholarly publishing and identify the most important and relevant sources in their field.

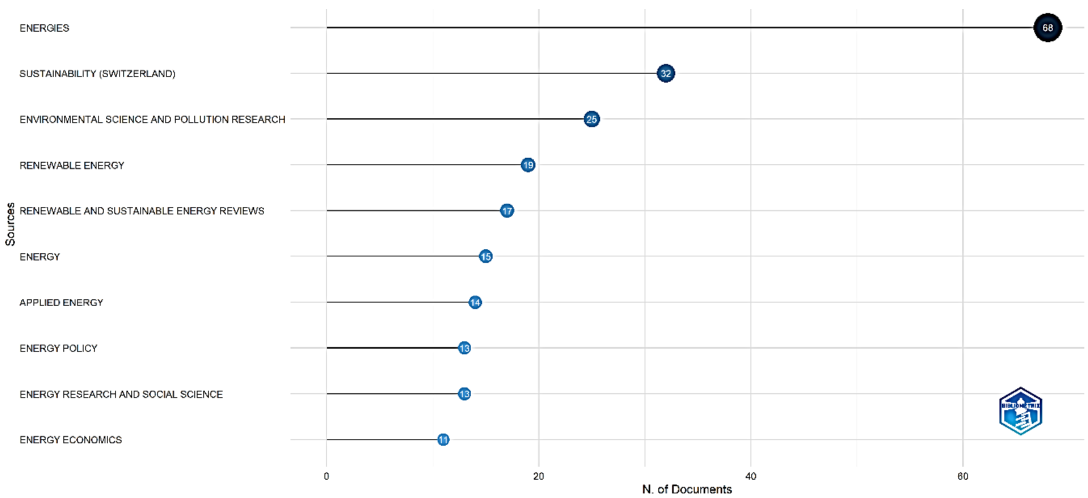

Figure 10. Most relevant sources

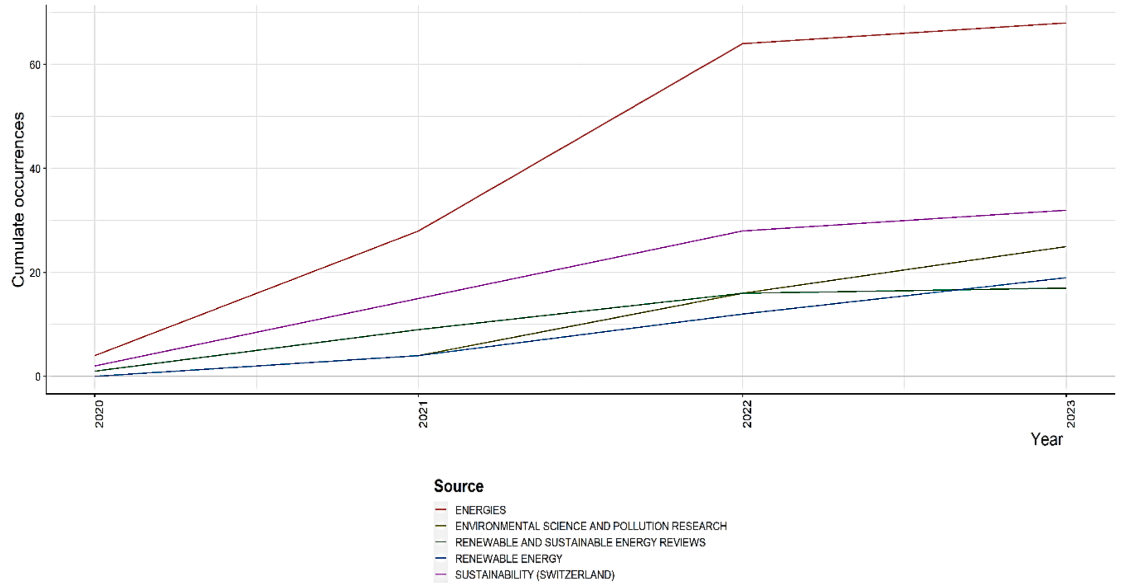

Figure 11. Sources production over time

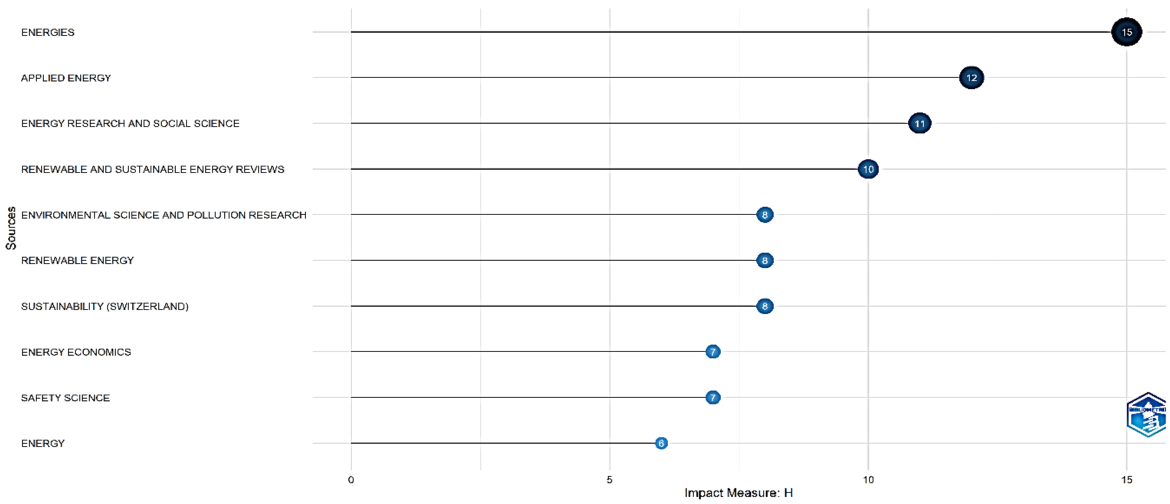

Figure 12. Sources impact by h-index

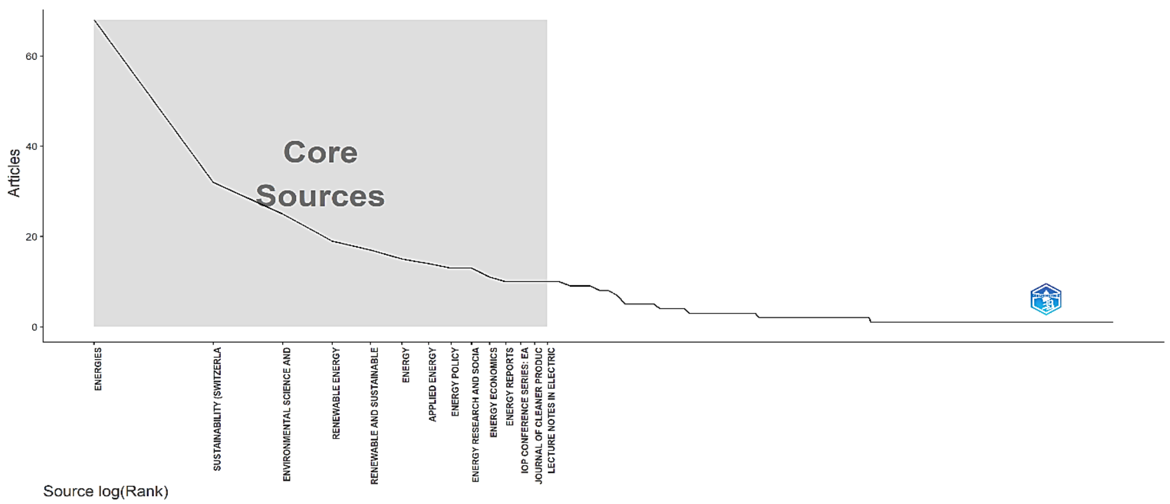

Figure 13. Core sources by Bradford’s law

3.5. Keywords

The word cloud visualizes the most frequently occurring author's keywords in a text corpus. Word clouds are created by analyzing the frequency and co-occurrence of keywords, where the size of each word represents its frequency or importance in the corpus. This analysis helps to identify the most common themes, topics, or issues regarding the effect of COVID-19 on renewable energy research. Figure 14 shows the terms of energy policy, alternative energy, sustainable development, investments, climate change, carbon dioxide, carbon, human, pandemic, and energy utilization, which are the top ten issues in this field.

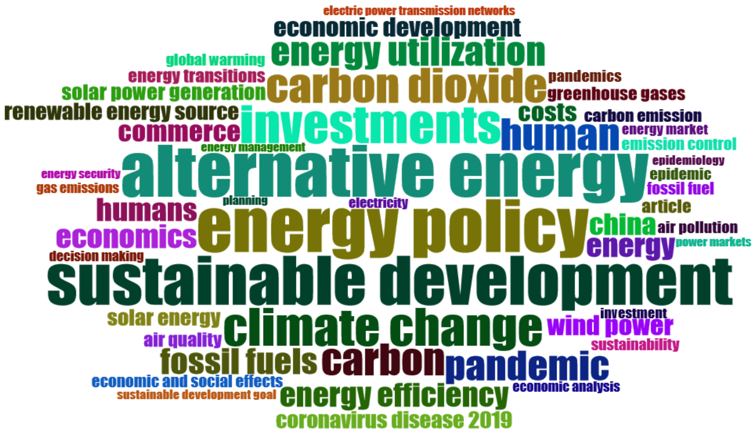

Figure 14. Wordcloud

After the analysis of country (AU_CO), affiliation (AU_UN), and keyword (DE), the correlation in these fields is shown in Figure 15. According to analyses, several countries and affiliations have shown strong collaboration on the effect of COVID-19 on renewable energy research. Some of the most vital collaboration networks include the United States and China. The United States and China have published research and have collaborated frequently on COVID-19 research, with several joint publications and partnerships between universities and research institutions. Collaboration networks have allowed for the sharing of data, expertise, and resources and have enabled researchers to work together toward combatting the COVID-19 effect, especially in renewable energy.

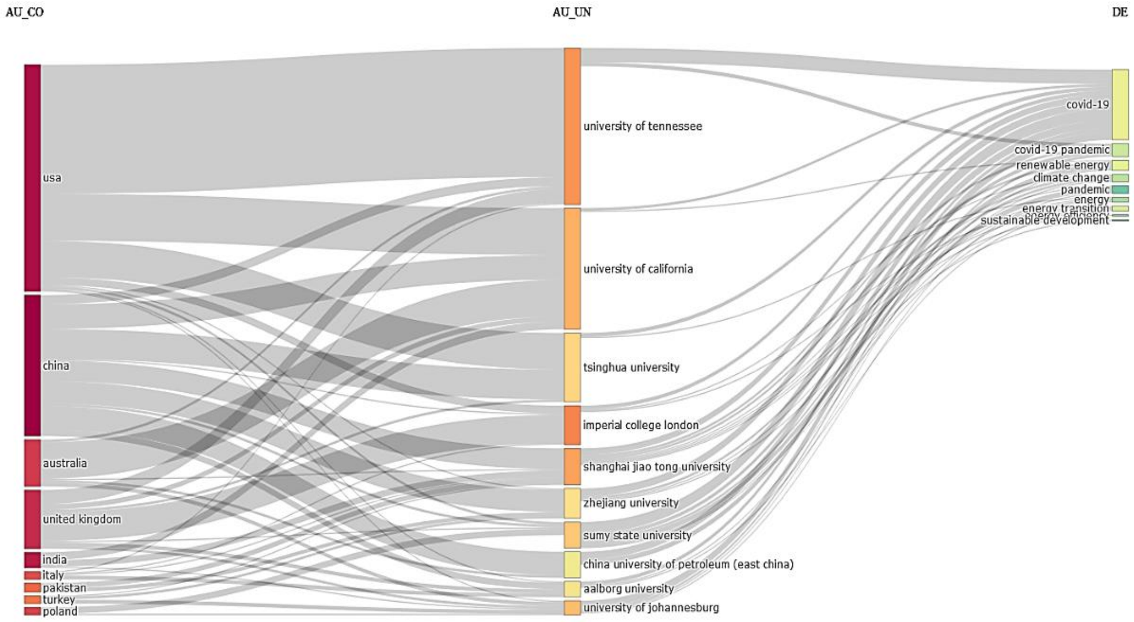

Figure 15. Three field plot

A co-occurrence network is one of the keyword analyses to visualize the relationships between author keywords based on their appearance. In a co-occurrence network, nodes represent keywords, and links represent their co-occurrence relationships. The thickness of the links indicates the strength or frequency of the co-occurrence relationship. At the same time, the size or centrality of the nodes represents their importance or influence in the network. This analysis can help researchers identify a research area's main themes or subfields based on their co-occurrence patterns. Figure 16 shows two significant clusters (blue and red) on the effect of COVID-19 on renewable energy research. The analysis identifies that renewable energy resources/renewable energy, investments, energy policy, and sustainable development have a strong relationship in the blue cluster. On the other hand, COVID-19, alternative energy, climate change, carbon, and air quality also have a strong relationship in the red cluster.

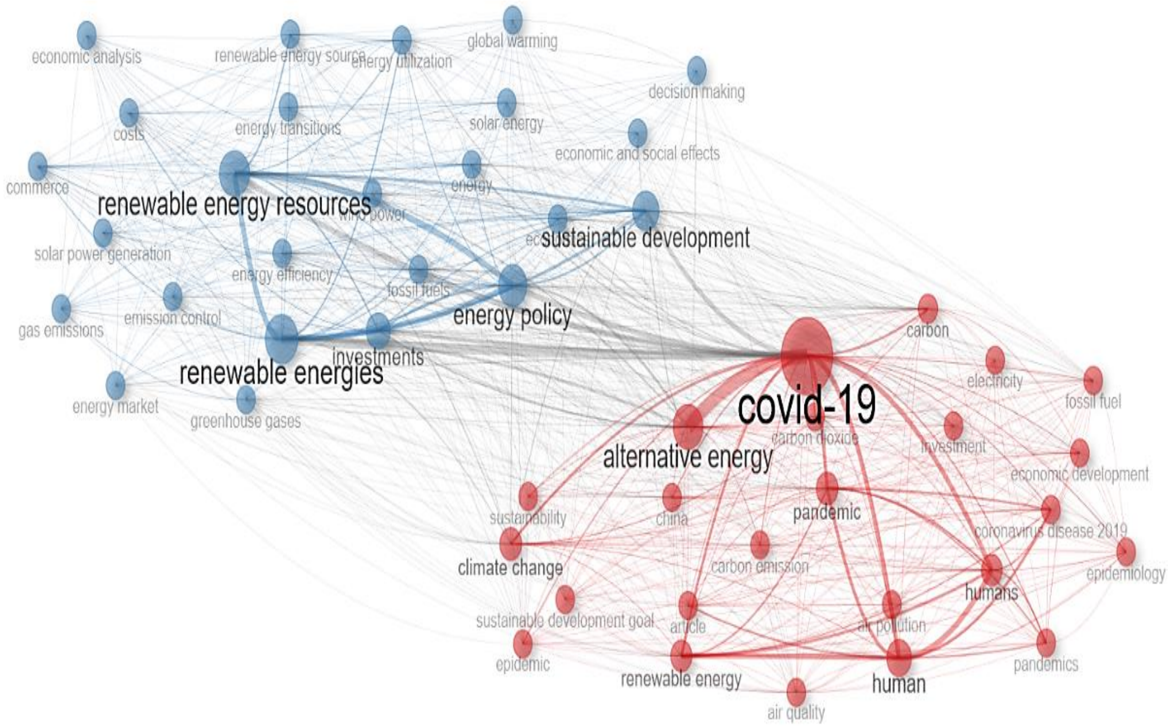

Figure 16. Co-occurrence network

3.6. Thematic map

Different types of research themes can be identified in a thematic map analysis. Figure 17 shows the keywords that appear only in basic and niche themes. Basic themes are the most common or fundamental themes related to a research area. This type of research has higher relevance but a low development degree. Basic themes can provide an overview of the main research areas within a field. Basic themes include a cluster of the energy transition, the COVID-19 pandemic, energy efficiency, and a cluster of COVID-19 renewable energy and climate change. Niche themes are more specialized or specific to a particular subfield within a research area. Niche themes can be identified as smaller clusters of publications or citations concentrated in a particular region or country. They can provide insights into the unique research interests of different scientific communities. This type of research has lower relevance but a higher development degree. Niche themes include a cluster of machine learning and forecasting and a cluster of energy consumption, economic growth, and CO_2 emissions. Figure 17 shows the unique cluster of SARS-CoV-2, solar energy, and coronavirus terms in central development and relevance degree. It means this cluster has a medium degree of development and relevance.

3.7. Trend topics

Trend topics analysis in bibliometric analysis depends on the research publications of that particular year. The yearly trend topics on the effect of COVID-19 on renewable energy research have evolved as the pandemic has progressed and new research has become available, as shown in Figure 18. Some critical trend topics over the past few years include the following. In 2020, the focus in the first year of the pandemic was primarily on disease control, virus, and healthcare policy to mitigate COVID-19. In 2021, the second year of the pandemic, cost and economic factors for coronavirus disease 2019 became a significant focus. There was also continued research on the long-term effects of COVID-19 and the impact of the pandemic on the economy. In 2022, the research focused on the correlation between COVID-19 and renewable energy resources. As of May 2023, COVID-19 research is still ongoing. Some key trend topics include methane, green economy, and wavelet analysis. Overall, the trend topics analysis reflects the evolution of the pandemic and the shifting priorities and concerns of researchers and organizations.

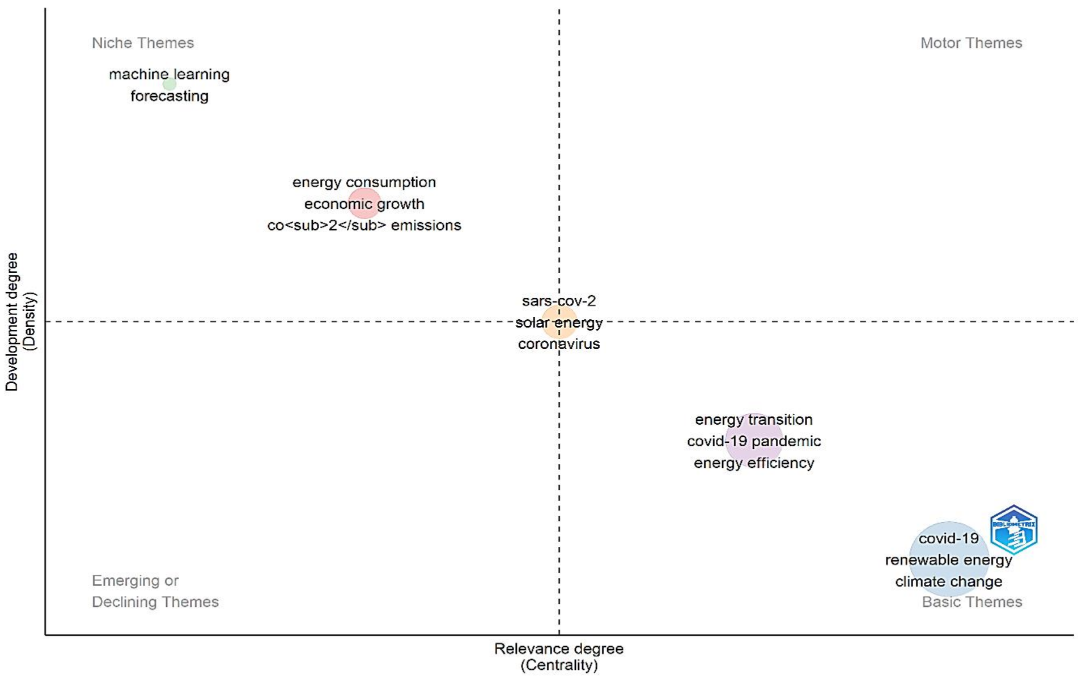

Figure 17. Thematic map

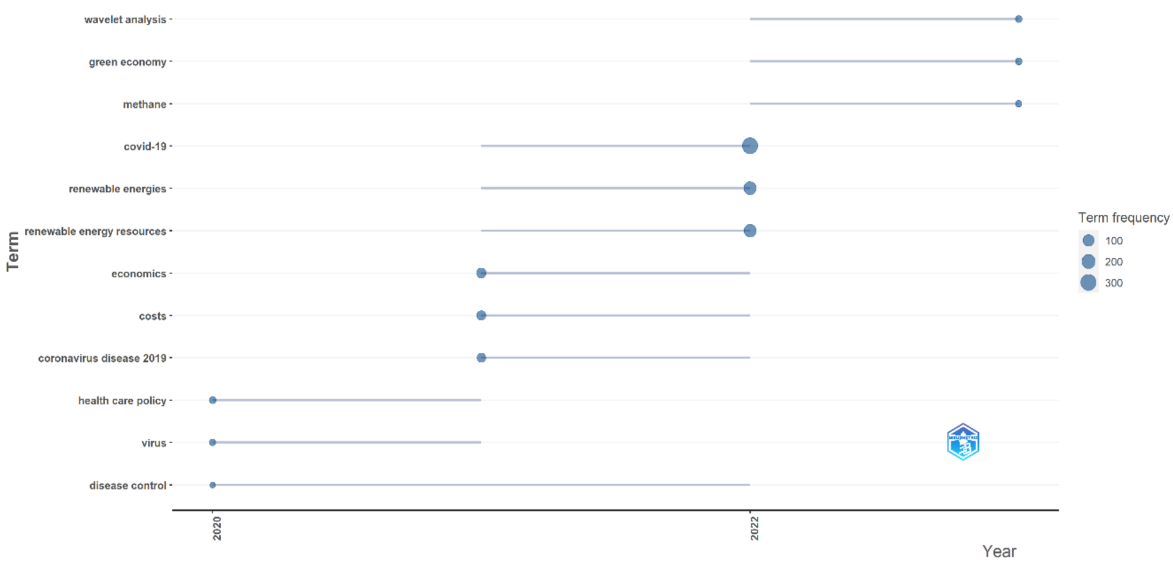

Figure 18. Trend topics

Thematic evolution involves using co-occurrence analysis to identify the keywords within the effect of COVID-19 on the renewable energy research field and then tracking how those keywords are used over time. This thematic evolution helps identify the evolution of research issues and evolution areas of interest.

Figure 19 visualizes the results, which show the relationships between the themes and clusters that have changed yearly from 2020-2021 to 2023. From 2020 to 2022, there was a focus on COVID-19 and economic growth, with increasing attention to energy security. From 2022 to 2023, there was a shift towards carbon emissions/CO_2 emissions, energy, SDGs, and green bonds.

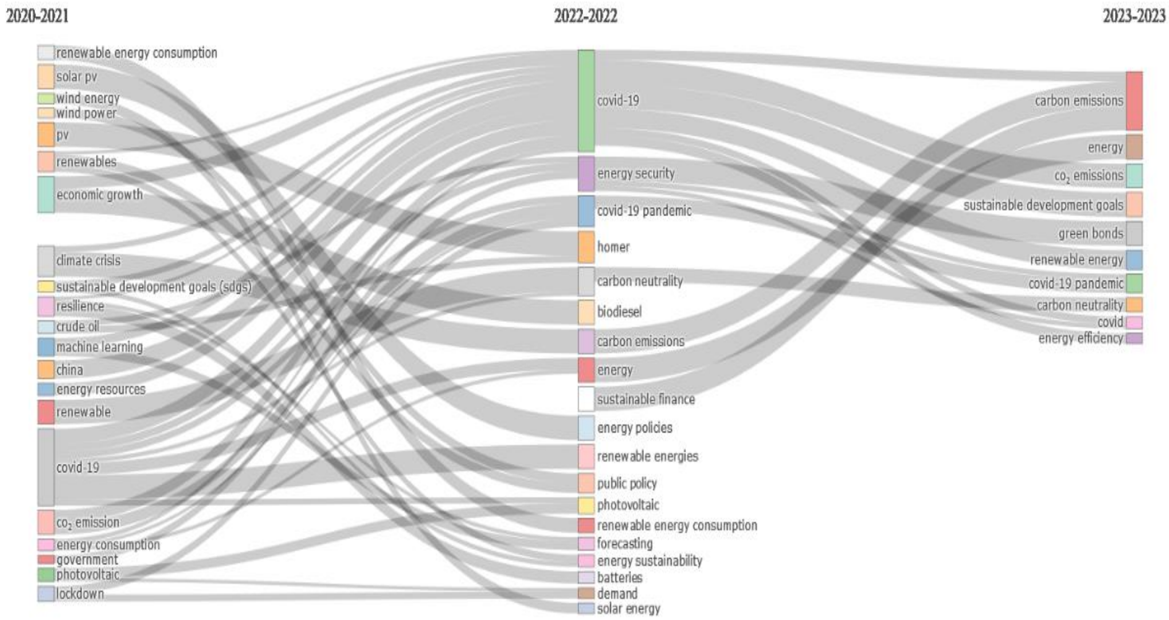

Figure 19. Thematic evolution

4. DISCUSSION

The number of research studies on COVID-19's effect on renewable energy has been rapidly advancing since the start of the pandemic. The thematic map analysis shows that niche themes include machine learning and forecasting clusters for future research. The energy sector has transformed since the COVID-19 pandemic lockdown was implemented. Forecasting is essential for decision-makers and can support predicting future conditions based on historical data. A study from [49] utilizes fractional grey prediction models and machine learning approaches to forecast seasonal electricity generation under COVID-19-induced lockdown in European countries. Another study from [50] employs advanced machine learning, such as the LightGBM, CatBoost, XGBoost, random forest (RF), and neural network models to predict oil prices during the COVID-19 pandemic by looking into stock markets, global environmental indexes (ESG), and renewable energy resources. Research from [51] also uses machine learning to integrate the Prophet model for self-updating and self-evaluated building load forecasting. Other topic clusters in Niche themes include energy consumption, economic growth, and CO_2 emissions. Study [52] employing regression analysis consists of the fixed effects methods, pooled OLS regression, panel cointegration tests, and Granger causality from 70 countries in the 1994 to 2013 period. The finding shows that large-scale foster investments in new and renewable energy are required to reduce CO_2 emissions significantly.

The trend topics on the effect of COVID-19 on renewable energy research have evolved as the pandemic has progressed. In 2020, the focus in the first year of the pandemic was primarily on disease control, virus, and healthcare policy to mitigate COVID-19. As of 2023, a critical recent trend topic is the impact of the COVID-19 pandemic on the green economy. The COVID-19 pandemic has positively and negatively impacted the green economy [53]. The pandemic has harmed some aspects of the green economy, particularly in the short term. Many renewable energy projects have been delayed or canceled due to disruptions in global supply chains, emissions, and financial challenges [54]–[56]. Similarly, some green jobs in sectors such as energy efficiency, public transportation, and sustainable tourism have been lost due to the economic downturn. On the other hand, COVID-19 has also created opportunities for the green economy to grow and expand. There has been a surge in demand for sustainable products and services as consumers become more conscious of their impact on the environment and public health [57]. Additionally, governments have used economic stimulus packages to invest in green infrastructure projects and create green jobs as part of their recovery plans. The pandemic has allowed governments, businesses, and individuals to prioritize transitioning to a low-carbon and sustainable economy. The thematic evolution identifies the cluster of themes, and clusters have changed yearly from 2020 to 2023. In 2023, there was a shift towards carbon emissions, SDGs, and green bond issues.

5. CONCLUSION

The number of studies on COVID-19 has rapidly grown since COVID-19 was the outbreak of a novel respiratory illness in Wuhan, China, in December 2019. The pandemic has caused widespread disruption, including in renewable energy research. This study aims to investigate the impact of the COVID-19 pandemic on renewable energy research by conducting a bibliometric analysis from the Scopus indexing database from 2020 to 2023. This study utilizes a bibliometric approach to examine the most relevant authors, affiliations, publication sources, keywords, thematic maps, and trend topics. The analysis will focus on the comprehensive overview of the published research and identify the potential future research.

The results show that the number of research studies related to COVID-19's effect on renewable energy will significantly increase from 2020. There are patterns of collaboration among researchers and the structure of scientific communities. China has had an influential impact of COVID-19 on renewable energy studies from organization and university affiliations, number of single and multiple country collaboration publications, funding sponsors, and most cited countries. The source analysis in the Scopus indexing database shows various types of publications, including articles, books, conference papers, reviews, data papers, editorials, letters, notes, and short surveys. The word clouds visualize the terms of energy policy, alternative energy, sustainable development, investments, climate change, carbon dioxide, carbon, human, pandemic, and energy utilization are the top issues in this field. The co-occurrence network identifies the relationship between the cluster of renewable energy resources, investments, energy policy, and sustainable development, and the cluster of COVID-19, alternative energy, climate change, carbon, and air quality has a strong relationship. The thematic analysis shows niche themes, including a cluster of machine learning and forecasting and a cluster of energy consumption, economic growth, and CO_2 emissions. The yearly trend topics on the effect of COVID-19 on renewable energy research have evolved as the pandemic has progressed and new research has become available. Some key trend topics include methane, green economy, and wavelet analysis. The keywords on the effect of COVID-19 on renewable energy research have evolved as the pandemic has progressed. As of 2023, a critical recent trend topic is the impact of the COVID-19 pandemic on a shift towards carbon emissions, energy, SDGs, and green bonds. This finding contributes to a comprehensive understanding of the impact of the COVID-19 pandemic on renewable energy research and a new direction for future research.

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