frontiers | Frontiers in Environmental Science

TYPE Systematic Review
PUBLISHED 03 July 2024
DOI 10.3389/fenvs.2024.1421990

Check for updates

OPEN ACCESS

EDITED BY
Le Wen,
University of Auckland, New Zealand

REVIEWED BY
Zhen Wang,
Huazhong Agricultural University, China
Muhammad Yousaf Raza,
Shandong Technology and Business University, China

*CORRESPONDENCE
Yanwen Wang,
wensomone@163.com

RECEIVED 23 April 2024
ACCEPTED 07 June 2024
PUBLISHED 03 July 2024

CITATION
Xu K, Yang M, Yang J, Nataliia B, Cai Y, Zhang H and Wang Y (2024), Mapping scholarly publications of energy conservation and emission reduction in support of the sustainable development goals (SDGs).
Front. Environ. Sci. 12:1421990.
doi: 10.3389/fenvs.2024.1421990

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Mapping scholarly publications of energy conservation and emission reduction in support of the sustainable development goals (SDGs)

Kewei Xu[1], Mingmei Yang[1], Jiamiao Yang[2], Butina Nataliia[1], Yuanyuan Cai[3], Hao Zhang[1] and Yanwen Wang[1]*

[1]School of Economics and Management, China University of Geosciences, Wuhan, China, [2]Changjiang Engineering Supervision Consulting Co., Ltd., (Hubei) of Changjiang Water Resources Commission, Wuhan, Hubei, China, [3]The College of Economics and Management, Beijing University of Chemical Technology, Beijing, China

In light of continuous advancements in science and technology, the global economy is experiencing rapid growth. However, this growth has been accompanied by significant depletion of natural resources and environmental degradation. Consequently, there is a burgeoning global emphasis on energy conservation, emissions reduction, and sustainable development. In this study, based on the Science Citation Index Expanded (SCIE) and Social Science Citation Index (SSCI) databases from 1990 to 2022, a statistical analysis of energy conservation and emission reduction in alignment with Sustainable Development Goals (SDGs)-related publications was undertaken using biblimometric methods. The findings reveal that (1) In recent years, there has been a discernible increase in global research on this subject, especially since 2009, with a sustained trend of exceeding 100 publications per annum. China prominently contributing to this domain, the proportion reached 34.2%, reflecting a growing emphasis on eco-friendly development trends. (2) Due to the burgeoning significance of energy conservation and emission reduction, there has been a notable escalation in research efforts pertaining to "Energy and Fuels," "Environmental Science" and "Green and Sustainable Science and Technology" and other related subjects. (3) Regarding the keyword analysis, "renewable energy" as the most frequently encountered term, often paired with "CO_2 emissions." This association underscores the pivotal role of renewable energy technologies in advancing green development initiatives and mitigating emissions. (4) China, United States and United Kingdom occupy central positions in terms of both paper publication volume and collaborative networks, collectively accounting for about 54.7%, and these countries are pivotal contributors to the scholarly discourse on sustainable development and environmental conservation. (5) From 1990 to 2022, the top 20 cited articles predominantly address diverse sub-goals of Sustainable Development Goal 7, with a common emphasis on enhancing energy efficiency, sustainability and renewable energy. These findings furnish valuable analytical insights for subsequent researchers investigating energy conservation and emission reduction as well as sustainable development endeavors.

KEYWORDS

sustainable development goals (SDGs), energy conservation, emission reduction, bibliometrics, co-occurrence relationship, network analysis

1 Introduction

In the process of industrialization, human society has undergone a continuous evolution, from the initial destruction of the ecological environment to subsequent endeavors aimed at protecting the environment and cultivating an awareness of energy conservation and emission reduction (Omer, 2009; Cao et al., 2024). From the 1972 World Environment Conference in Stockholm to the 2009 Copenhagen Agreement, and then to 2015 Paris Climate Agreement, most countries built consensus on environmental protection, energy conservation and emission reduction, and achieve some positive results in political, economic, scientific and technological fields (Figure 1). In September 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, which sets out 17 goals for the international community to achieve a sustainable society (United Nations, 2015). Achieving equal access to affordable, reliable, sustainable, and modern energy is a key objective of the United Nations' initiatives for a sustainable future, encapsulated in Sustainable Development Goal (SDG) 7. This goal underscores the importance of ensuring universal access to energy, recognizing its fundamental role in fostering development, improving living standards, and promoting sustainability (Elavarasan et al., 2022; He et al., 2022; Ahmad et al., 2023). For policymakers to assess and monitor the performances towards the SDGs, including SDG 7, sets of quantifiable indicators corresponding to the respective targets have been developed. More specifically, SDG seven is specified through five targets defined as (7.1) ensuring universal access to affordable, reliable, and modern energy services, (7.2) increasing renewable energy share, (7.3) double global rate of energy efficiency improvement, (7.a) enhancing international cooperation on clean energy research and technology, and (7.b) expanding infrastructure and developing technologies.

In recent years, countries worldwide have been proactively implementing measures to address environmental challenges, including issues such as global warming and energy shortages. The recognition of these challenges has spurred a global commitment to finding sustainable solutions and mitigating the impact of environmental problems. Energy conservation and emission reduction constitute key measures in addressing global climate change (Eskander and Fankhauser, 2020; Roe et al., 2021; Zhao et al., 2022). By mitigating greenhouse gas emissions, particularly carbon dioxide, it can be decelerated the pace of global warming and alleviated the frequency and intensity of extreme weather events and natural disasters (Sovacool et al., 2021; Su et al., 2024). Additionally, energy conservation and carbon reduction initiatives are effective in reducing the emission of air pollutants. This not only helps improve air quality but also contributes significantly to addressing environmental issues such as haze and acid rain (Mwangi et al., 2015; Sofia et al., 2020; Qian et al., 2021). At the same time, it can improve the efficiency of energy utilization and optimize the allocation of resources, and these measures will reduce economic costs and enhance competitiveness (deLlano-Paz et al., 2015; May et al., 2016; Raza and Tang, 2022). Moreover, the extension of the useful life of limited resources is an additional sustainability benefit, aligning with the principles of responsible resource management and long-term

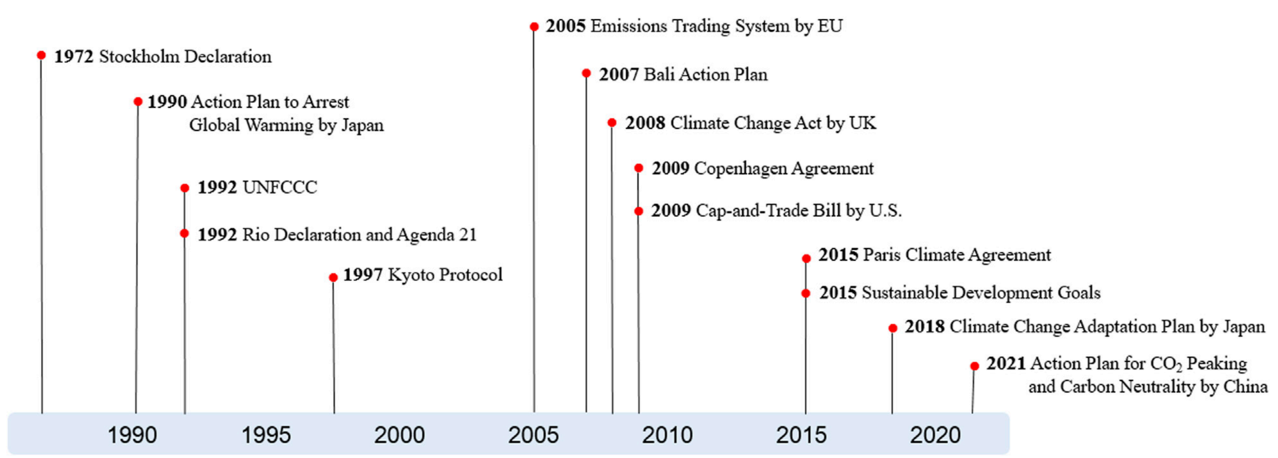

FIGURE 1
Chronology of key policy events related energy conservation and emission reduction.

environmental stewardship (Schultmann and Sunke, 2007; Kaygusuz, 2012).

A substantial body of research has focused on both of the SDGs and energy conservation over the past several decades (McCollum et al., 2018; Omer and Noguchi, 2020; Elavarasan et al., 2023). These studies aim to understand how energy conservation practices align with and contribute to the achievement of sustainable development, given energy is a critical enabler for economic growth, social wellbeing, and environmental sustainability (Ganda and Ngwakwe, 2014; Guzman-Sanchez et al., 2018; Zakari et al., 2022). Researchers play a pivotal role in contributing solutions and innovations to address the myriad challenges on the pathway to achieving the 2030 agenda outlined by the SDGs (Malhotra et al., 2022; Lohani et al., 2023). Their work spans various fields, from technology and science to social sciences and policy research, aiming to provide insights and strategies that can guide effective actions towards sustainable development (Santika et al., 2019; Xu et al., 2023). Meanwhile, there is a growing body of literature that explores energy conservation and carbon reduction. To comprehend the factors contributing to the increase in CO_2 emissions, certain scholars analyze the associated driving forces from various perspectives (Mohmmed et al., 2019; Zhang et al., 2019; Balezentis, 2020; Xiuhui and Raza, 2022). In contrast to industrialized nations, CO_2 emissions resulting from energy use have experienced a substantial increase in newly industrialized economies since the 1990s, and these countries will encounter more acute challenges, encompassing climate change and energy shortages, posing greater hurdles in achieving sustainable development (Mitić et al., 2023). The majority of countries generally hold the belief that embracing a low-carbon economic development trajectory is integral to attaining carbon emission reduction and fostering sustainable development (Blohmke, 2014; Wimbadi and Djalante, 2020). While previous studies have provided insights into energy conservation and emission reduction, relying solely on theoretical analysis may not offer a comprehensive understanding of the current status and evolving trends within this research domain. Hence, it is essential to incorporate both quantitative and qualitative analyses in conducting a systematic and comprehensive literature review of energy conservation and emission reduction in achieving the SDGs.

Bibliometrics involves the quantitative examination of publications, citations, and other bibliographic data to provide insights into patterns, trends, and the impact of research within a specific discipline or academic domain (Abramo et al., 2011; Rousseau et al., 2018; Ho et al., 2020). This methodology is widely used in scholarly research to assess the productivity and influence of researchers, journals, and institutions, as well as to analyze the evolution of scientific knowledge over time (Bhatt et al., 2020; Sweileh, 2020). Additionally, by employing mathematical methods for statistics and visualization, bibliometrics can effectively capture the network structure of a research field. This involves analyzing relationships among various elements such as countries, authors, publications, keywords, and etc. Through network analysis, bibliometrics provides insights into the interconnections and collaborations within the scientific community, revealing patterns of knowledge dissemination and collaboration dynamics (Donthu et al., 2021; Goodell et al., 2023). This quantitative approach contributes to a deeper understanding of the structure and evolution of research fields.

Therefore, we use bibliometric analysis to explore global research trends on energy conservation and emission reduction in support of the SDG 7 using the Science Citation Index Expanded (SCIE) and Social Science Citation Index (SSCI) databases from 1990 to 2022. The objective of this study is to construct a systematic analysis for both quantitative and qualitative evaluation of the impact of research on energy conservation and emission reduction, with a particular focus on contributing to the realization of SDG 7 and its associated targets. More specifically, our research aimed to answer the following questions:

- What are the overall volume, growth patterns, and geographical distribution of scholarly outputs concerning energy conservation and emission mitigation within the framework of SDGs?
- What are the principal subjects, keywords, and highly cited articles that stand out within the discourse on energy conservation and emission reduction in the context of SDGs?
- Which countries demonstrate the highest productivity in generating scholarly outputs, and which among them serve as central hubs in the network of national collaborations pertaining to energy conservation and emission reduction within the scope of SDGs?

Our study helps to elucidate the prospective trajectory of research endeavors in the domains of energy development, utilization, and carbon emission mitigation, aligning with the objectives of the SDGs. The findings of our investigation provide valuable scholarly references for researchers within this domain, and hold the potential to guide policymakers in crafting strategies and developmental targets concerning energy exploration and utilization.

2 Materials and methods

2.1 Data collection

In this study, bibliographic data were collected on the Web of Science (https://mjl.clarivate.com/search-results) on 8 November 2023. Web of Science is a comprehensive platform encompassing various literature search databases tailored to support scientific and scholarly research. At its core is the Web of Science Core Collection, a premier resource containing over 21,000 peer-reviewed, high-quality scholarly journals from around the globe, including Open Access journals (Wang et al., 2022). Additionally, it includes thousands and thousands of conference proceedings and editorially selected books. Thus, we obtained data sources from the SCIE and SSCI in the Web of Science. "Sustainable Development Goal* 7" OR "SDG 7" OR "SDG7" OR "sustainab* energy*" OR "clean* energ*" OR "energ* access*" OR "affordab* energ*" OR "energ* affordab*" OR "renewabl* energ*" AND "Carbon dioxide release" OR "Carbon dioxide emission*" OR "CO2 release" OR

"CO2 emission*" OR "Carbon release" OR "Carbon emission*" OR "carbon dioxide release" OR "carbon dioxide emission*" were selected as search terms in the titles, abstracts and keywords of journal articles, and the original data can be seen from Supplementary Data. Initially, we gathered a total of 13,536 academic documents. Subsequently, we created a relational database to store comprehensive information on each piece of literature. During the preprocessing phase, several steps were conducted to ensure data quality and consistency. These steps included deduplication to eliminate duplicate documents, data standardization to ensure uniformity across documents, and text parsing to extract essential information such as authors, titles, abstracts, and keywords. These preprocessing steps were crucial for ensuring the high quality, consistency, and comparability of the dataset, laying a solid foundation for subsequent research endeavors. It is important to note that publications originating from England, Scotland, Northern Ireland, and Wales were grouped under the United Kingdom (UK), while Hong Kong, Macau, and Taiwan were treated separately from mainland China due to differences in their political systems.

2.2 Research methodology

Bibliometric methods can identify research hotspots and evolution in specific disciplines with a large number of publications (Fahimnia et al., 2015). Among them, co-word analysis facilitates a systematic and quantitative examination of literature in the domains of energy efficiency and carbon reduction. This method provides a comprehensive understanding of the current state of research, aids in identifying key themes and trends, and supports strategic planning for future research endeavors aimed at achieving the SDGs. Social network analysis, on the other hand, elucidates and quantifies relationships and interactions within the academic community. It provides an in-depth understanding of academic citation patterns, collaborative networks, and knowledge dissemination pathways, thereby identifying high-impact papers, authors, and research institutions. Additionally, social network analysis can reveal trends in global research collaboration, identify key research partners, and assess the intensity of international collaboration by analyzing the collaboration networks of various countries, thus highlighting critical nodes and pathways. Meanwhile, the Sankey diagram analysis method provides a clear and easily understandable visualization tool, effectively displaying complex multi-factor associative data. It reveals the research hotspots and trends, thereby aiding in the analysis of different countries' focal points and contributions in the field of research. This method significantly enhances data interpretability and analysis efficiency. Consequently, in this study we mainly used data visualization methods such as co-word analysis, social network analysis and Sankey diagram analysis to show the results of research output performance, subject categories, keywords analysis, country productivity and collaborations, highly cited articles and etc. Through these analytical tools, we were able to gain an in-depth understanding of the research dynamics and trends in the field of energy conservation and emission reduction aligning with the objectives of the SDG 7, and revealed the cooperative relationship between different countries, disciplines and key research directions, and these charts can show the research pattern within the realm of energy conservation and emission reduction as well as SDG 7 in a more intuitive way.

Co-word analysis utilizes the co-occurrence of word pairs of noun phrases in a literature set to determine the relationship between topics in the discipline represented by that literature set (Callon et al., 1991; Ma et al., 2019). It is usually assumed that when two topics are more related, their keywords will appear more often in the same piece of literature. Therefore, we constructed a co-word network by counting the frequency of occurrence of the topic words two by two in the same document in a set of literature. In this network, nodes represent various topics, and the connections between nodes signify the relationship between these topics. The strength of these connections reflects the degree of correlation between topics (Braam et al., 1991).

In bibliometrics, social network analysis is an important methodology used to study collaborative relationships among scholars, information flows, and the structure and evolution of scholarly communities in academia. The core idea of social network analysis is to consider scholars or literature as nodes in a network, while their collaborative or citation relationships are considered as connections or edges in the network. The more times a node acts as this type of "mediator," the more central it becomes (Chen et al., 2014; Hou and Wang, 2021). By analyzing the structure and properties of these nodes and edges, information about the patterns of cooperation, information dissemination paths, and key nodes in the academic community can be revealed.

The Sankey diagram analysis method is used to visualize and analyze the flow and transformation processes of resources, energy or quantities in complex systems (Lee et al., 2022). It could show the processes in order to visualize and understand the relationships and interactions between the various parts of the system. A Sankey diagram usually consists of a series of nodes and flows connecting these nodes. Nodes represent different states, processes, or categories, and flows represent transfers or flows between nodes. By adjusting the size of the nodes and the width of the flows, the quantitative or proportional relationships between different states can be reflected.

2.3 Analytical tools

By systematically collecting academic literature related to SDG 7 and energy conservation and emission reduction research, we conducted an extensive search using academic databases, on the basis of which we carried out the necessary data preprocessing. Subsequently, visualization tools such as VOSviewer and R biblioshiny were utilized for literature analysis to explore the distribution of the number of documents, collaborative networks between authors and countries, and co-occurrence relationships between keywords (Merigó et al., 2018; Do et al., 2021). Spatial analysis was also carried out by using geographic information system software such as ArcGIS, which combines literature data with geographic information to show the spatial distribution of literature in the form of maps. Through geographic information visualization, it is possible to visualize the level of research activities

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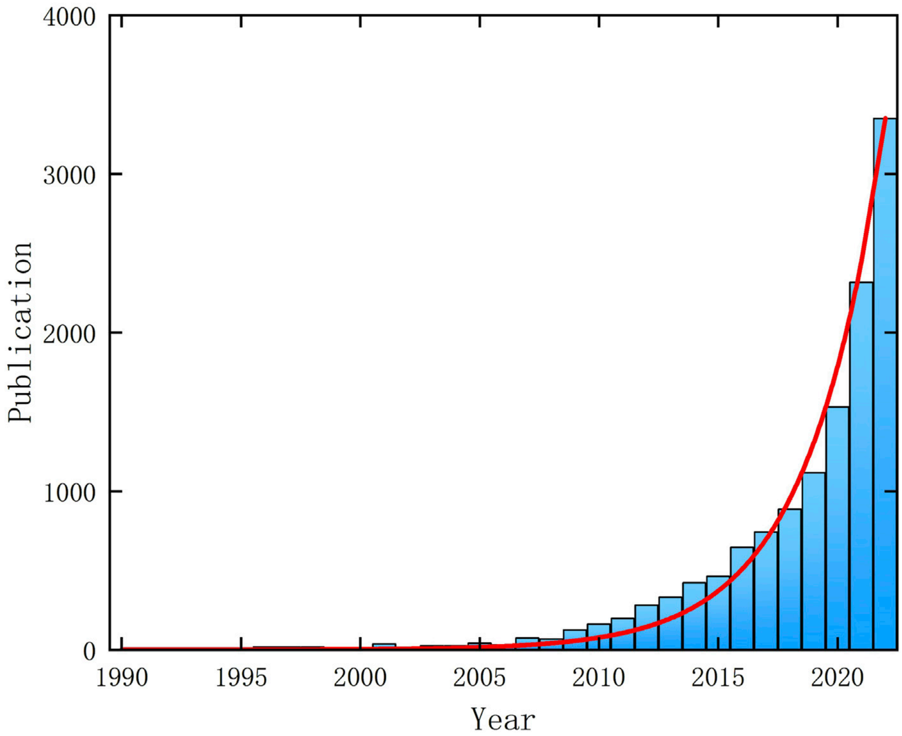

FIGURE 2
Number of publications from 1990 to 2022. Red line represents trend line.

and key research areas in different regions on SDG 7 and energy conservation and emission reduction.

3 Result and discussion

3.1 Research output performance

Figure 2 illustrates the correlation between the quantity of scholarly articles pertaining to energy conservation and emission reduction in support of the SDG 7 and their respective publication years. The fluctuation in publication counts across different years enables insights into the developmental trajectory of research within the field or discipline. An escalating trend in publication numbers suggests an expansion of research activities and heightened attention and investment in the respective domain. It can be seen from Figure 2, over successive years, there is a noticeable increase in the quantity of published articles. Between 1990 and 2008, scholarly output remained modest, consistently below 100 publications annually. However, the result indicates that research on energy conservation and emission reduction in support of the SDGs has experienced notable growth in publication output since 2009, consistently surpassing 100 publications per year. A significant milestone was reached in 2019, marked by an annual publication count surpassing 1,000 articles. Notably, in recent years, the growth rate of scholarly output has accelerated, particularly evidenced by the remarkable 51.37% increase in 2021. This trend has culminated in an annual output exceeding 1,000 publications in the preceding 2 years. As global economic development progresses, numerous countries are increasingly prioritizing ecological environments. This trend has resulted in a heightened emphasis on environmental protection, energy conservation, emissions reduction, and associated action measures. Meeting the objectives outlined in the SDGs necessitates a focused and collaborative endeavor from government bodies responsible for energy conservation and air pollution control. It outlines the necessary actions at both international and national levels to accomplish this objective.

The quantification of published scholarly works serves as a fundamental metric for assessing a country's research productivity and engagement within a specific academic domain. A heightened volume of publications typically signifies enhanced research capabilities and influence within said domain. Comparative analysis of publication outputs across different countries/territories allows for insights into global research activity distribution, thereby facilitating assessments of relative competitiveness and professional prowess. The geographical distribution of published articles in this field can be seen from Figure 3. Distinct colors symbolize varying numbers of documents in diverse geographic regions, with deeper colors indicating a higher volume of published articles in those areas. Figure 3 illustrates that articles focusing on energy conservation and emission reduction in alignment with SDGs are primarily concentrated in China, United States, United Kingdom, Turkey, and Pakistan. The research prowess of India, Germany, Australia, Malaysia, and other nations is also notably prominent in this domain. Among them, China is the country with the largest number of publications. There is a total of 4,626 articles published in China which accounts for 34.2% of the total

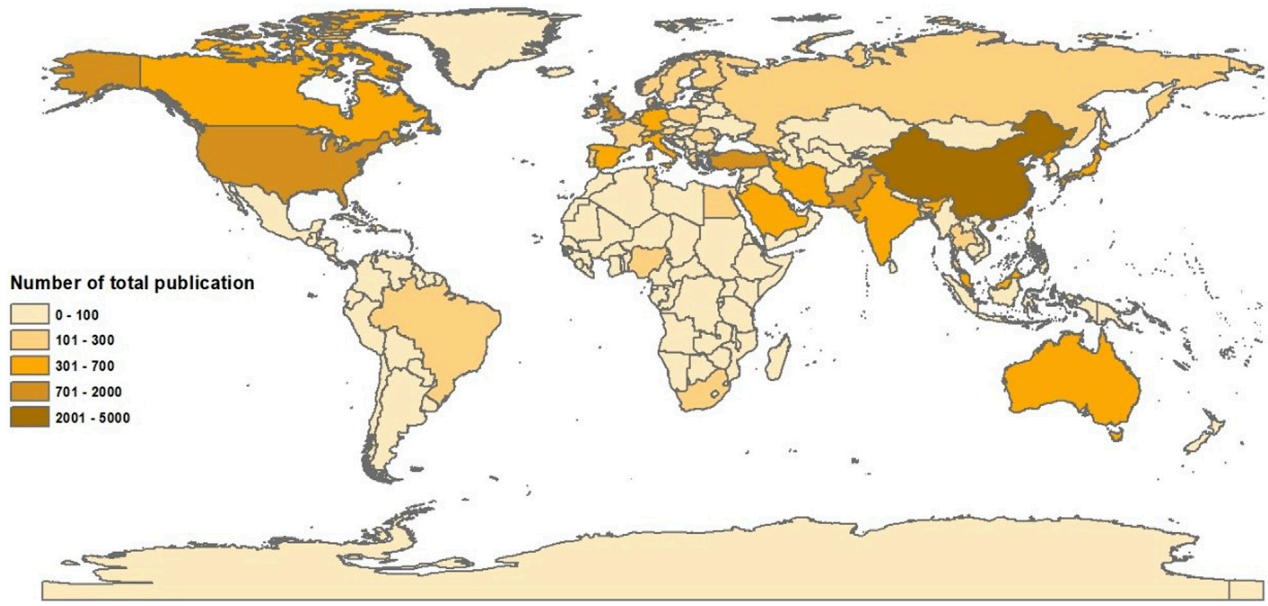

FIGURE 3
Geographical distributions of publications from 1990 to 2022.

number of articles. Second and third are the United States and United Kingdom with 11.9% and 8.6% of the total number of articles, respectively. The dataset generated herein establishes linkages between countries or territories and their respective publication counts.

Table 1 encapsulates the thirty most prolific countries/territories in terms of scholarly output. Among the top 30 countries in terms of scholarly output, 14 are situated within the European region, with 11 hailing from Asia. North America is represented by two countries, while Australia, Africa, and South America each contribute one country to this cohort. Prominently, China, United States, United Kingdom, Turkey, and Pakistan emerged as the top five countries, surpassing other nations in terms of scholarly output. China led the rankings with the highest number of publications, totaling 4,626 papers. Notably, China emerges as the foremost contributor both in total publication volume and in the number of autonomous (2,386) and collaborative publications (2,240). Subsequently, the United States emerged as the second leading contributor with 1,616 papers, among which 634 were authored individually and 982 were the result of international collaborations. Following closely, the United Kingdom contributed 1,160 publications, comprising 385 solo-authored papers and 775 papers resulting from international collaborations. Noteworthy observations reveal that among these nations or territories, only China, South Korea, Brazil, and Poland exhibit a higher proportion of autonomous outputs compared to collaborative ones. Furthermore, within the top ten contributors, Pakistan and Saudi Arabia exhibit the highest count of collaborative outputs.

As indicated in Figure 3; Table 1, China led in publication output, and securing the top position during the period from 1990 to 2022. Other highly productive countries included predominantly developed nations or emerging large developing countries, such as the United States, United Kingdom, Turkey, Pakistan, and India. This implied that economic development could significantly influence scientific investment in energy conservation and carbon reduction, particularly in major energy-consuming countries with high levels of economic development, such as China and India. As China grapples with escalating energy, resource, and environmental challenges, the government has progressively acknowledged the significance of shifting the economic growth paradigm and refining the industrial structure to prioritize energy conservation and emissions reduction (Jiang and Raza, 2023). Since 2006, the Chinese government has instituted obligatory objectives for energy conservation and emission reduction, and integrating them into the nation's medium- and long-term strategies for economic and social advancement (Wang et al., 2024). In 2020, China officially announced its objective of reaching the peak of carbon emissions by 2030 and attaining carbon neutrality by 2060 (Liu et al., 2022). More specifically, by 2030, substantial advancements are expected in the comprehensive green transformation of economic and social development. Carbon dioxide emissions per unit of GDP are projected to decrease by over 65% compared to 2005 levels (Zhang et al., 2016; Liu et al., 2022). The proportion of non-fossil energy consumption is anticipated to reach approximately 25%, with carbon dioxide emissions peaking and subsequently declining steadily (Zhang et al., 2017). By 2060, energy utilization efficiency will reach internationally advanced levels, with non-fossil energy consumption surpassing 80%, and successfully achieving carbon neutrality goals (Zeng et al., 2022). Meanwhile, the Chinese government is dedicated to partnering with nations worldwide on energy conservation and emissions reduction initiatives aimed at combatting climate change and global warming.

TABLE 1 The 30 most productive countries/territories.

Country	TP	Single-country		Internationally-collaborated	
		SP	SP(%)	CP	CP(%)
China	4,626	2,386	51.58	2,240	48.42
United States	1,616	634	39.23	982	60.77
United Kingdom	1,160	385	33.19	775	66.81
Turkey	1,070	459	42.90	611	57.10
Pakistan	972	123	12.65	849	87.35
India	699	325	46.49	374	53.51
Germany	588	267	45.41	321	54.59
Australia	585	199	34.02	386	65.98
Malaysia	549	134	24.41	415	75.59
Saudi Arabia	539	74	13.73	465	86.27
Spain	529	225	42.53	304	57.47
Italy	476	227	47.69	249	52.31
Canada	447	124	27.74	323	72.26
Iran	423	193	45.63	230	54.37
South Korea	406	228	56.16	178	43.84
Japan	398	165	41.46	233	58.54
Netherlands	293	74	25.26	219	74.74
France	292	55	18.84	237	81.16
Taiwan	262	107	40.84	155	59.16
Poland	241	129	53.53	112	46.47
Nigeria	238	53	22.27	185	77.73
Sweden	229	71	31.00	158	69.00
Portugal	208	95	45.67	113	54.33
Russia	207	28	13.53	179	86.47
Denmark	203	53	26.11	150	73.89
Brazil	201	117	58.21	84	41.79
Bangladesh	197	27	13.71	170	86.29
Finland	191	82	42.93	109	57.07
U Arab Emirates	181	33	18.23	148	81.77
Greece	178	83	46.63	95	53.37

Note: TP, total publication; SP, single-country publication; CP, internationally collaborated publication.

3.2 Subject categories

Examining the subject content of research literature serves as a valuable approach in gauging the level of scholarly activity within specific fields and the breadth of coverage undertaken by researchers. Such analysis unveils prevalent research trends and focal areas within a given domain, facilitating rapid comprehension of its developmental trajectory and identification of underexplored or ripe for further investigation topics.

As presented in Table 2, the thematic analysis delineates that out of the total publications, 6,736 articles are classified under the subject category of “Energy and Fuels,” comprising 49.76% of the total corpus. Following closely, “Environmental Sciences” encompasses 4,220 papers, constituting 31.18% of the overall scholarly output. “Green and Sustainable Science and Technology” emerges as the

TABLE 2 Top 20 productive subjects, 1990–2022.

Rank	Subject	TP	TP R (%)
1	Energy and Fuels	6,736	49.76
2	Environmental Sciences	4,220	31.18
3	Green and Sustainable Science and Technology	4,213	31.12
4	Environmental Studies	1,507	11.13
5	Engineering, Chemical	1,150	8.50
6	Engineering, Environmental	1,098	8.11
7	Thermodynamics	1,069	7.90
8	Economics	1,062	7.85
9	Chemistry, Physical	429	3.17
10	Engineering, Electrical and Electronic	399	2.95
11	Mechanics	309	2.28
12	Materials Science, Multidisciplinary	306	2.26
13	Chemistry, Multidisciplinary	282	2.08
14	Construction and Building Technology	246	1.82
15	Electrochemistry	220	1.63
16	Engineering, Civil	211	1.56
17	Multidisciplinary Sciences	183	1.35
18	Meteorology and Atmospheric Sciences	169	1.25
19	Engineering, Mechanical	161	1.19
20	Regional and Urban Planning	159	1.17

Note: TP, is the number of total publications; TP R (%) is the ratio of the number of one subject's publications to the total number of publications.

third most prevalent thematic category, representing 31.12% of the total publications, with a count of 4,213 papers. These top three thematic categories exhibit a quantitative hierarchy in terms of publication volume. Subsequently, the thematic categories from fourth to eighth form the second quantitative level. These include "Environmental Studies," "Engineering, Chemical," "Engineering, Environmental," "Thermodynamics" and "Economics." Each of these categories comprises more than 1,000 papers, accounting for approximately 10% of the total corpus. Conversely, the subsequent thematic subjects exhibit significantly lower publication counts, with numbers falling below 1,000 and proportions reflecting a markedly reduced significance in the overall scholarly output.

Due to the emergence of energy conservation and emissions reduction as a multidisciplinary hot topic in academic research in the past decades, it incorporates diverse disciplines from both natural and social sciences. Among them, research on energy and fuels, green sustainable science and technology, environmental science, and other related subjects is extensive. An increasing number of nations are recognizing that economic expansion achieved through the depletion of costly energy resources and environmental degradation is not sustainable in the long term. Both developed and developing nations acknowledge the grave threat posed by environmental issues to human survival and development, as well as the pressing need to address them. Extensive research in the subject of environmental science has been undertaken to chart a course towards resolving these issues, resulting in some consensus. The widely embraced "green sustainable development strategy" recognizes the imperative of addressing environmental concerns alongside economic development, while also acknowledging that the primary responsibility lies with industrially developed countries, either directly or indirectly.

3.3 Keywords analysis

For a more profound examination of publication content, keyword analysis is considered a crucial aspect, as it enables the identification of primary research topics. Rectangular treemap analysis serves as a pivotal data visualization technique employed for hierarchical data representation. Within a rectangular treemap, data is partitioned into numerous rectangles, where each rectangle symbolizes a distinct data unit, and its dimensions and placement reflect the relative relationships among these units. The size of the rectangle corresponds to the number and proportion of keywords, with larger rectangles indicating a greater abundance and significance of keywords. Illustrated in Figure 4, an examination of the most frequently occurring keywords across all publications reveals 30 distinct keywords. Notably, "renewable energy" emerges

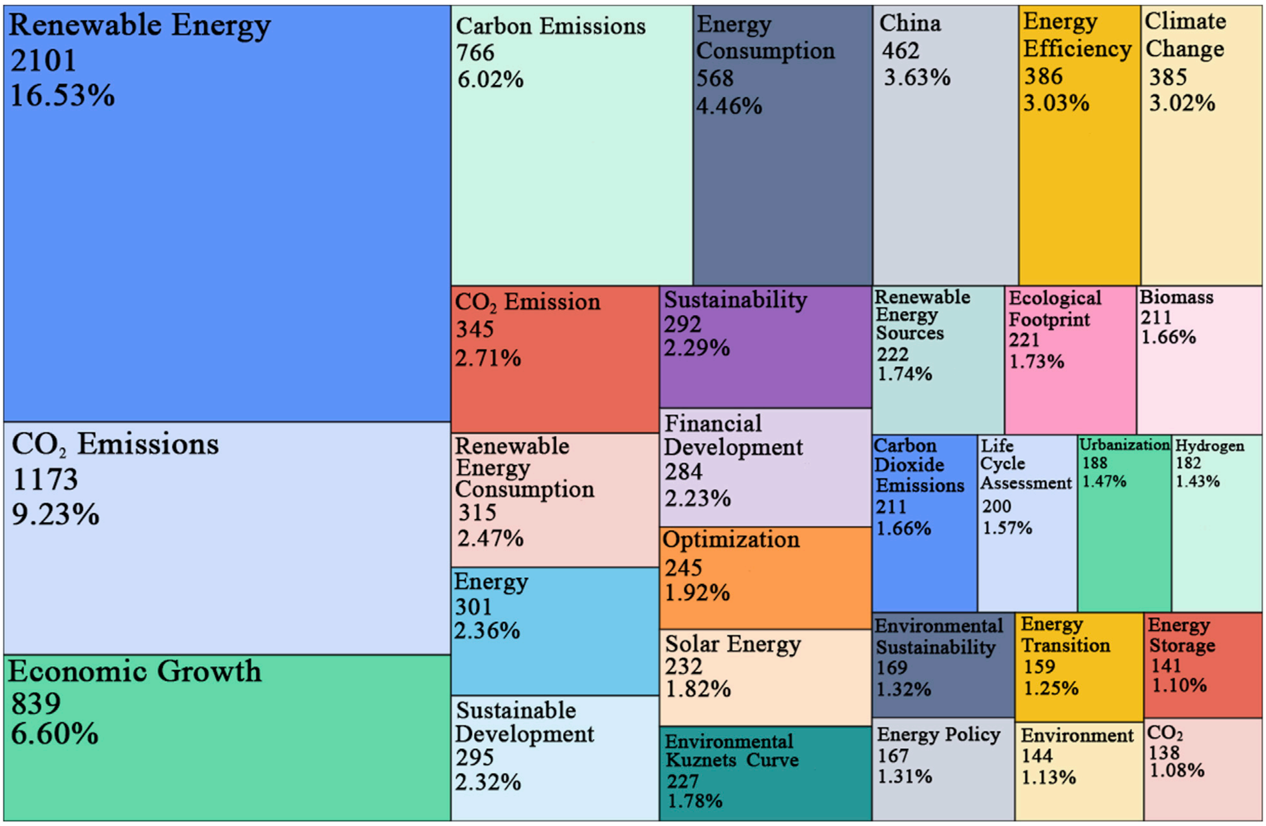

FIGURE 4
Keywords rectangular treemap.

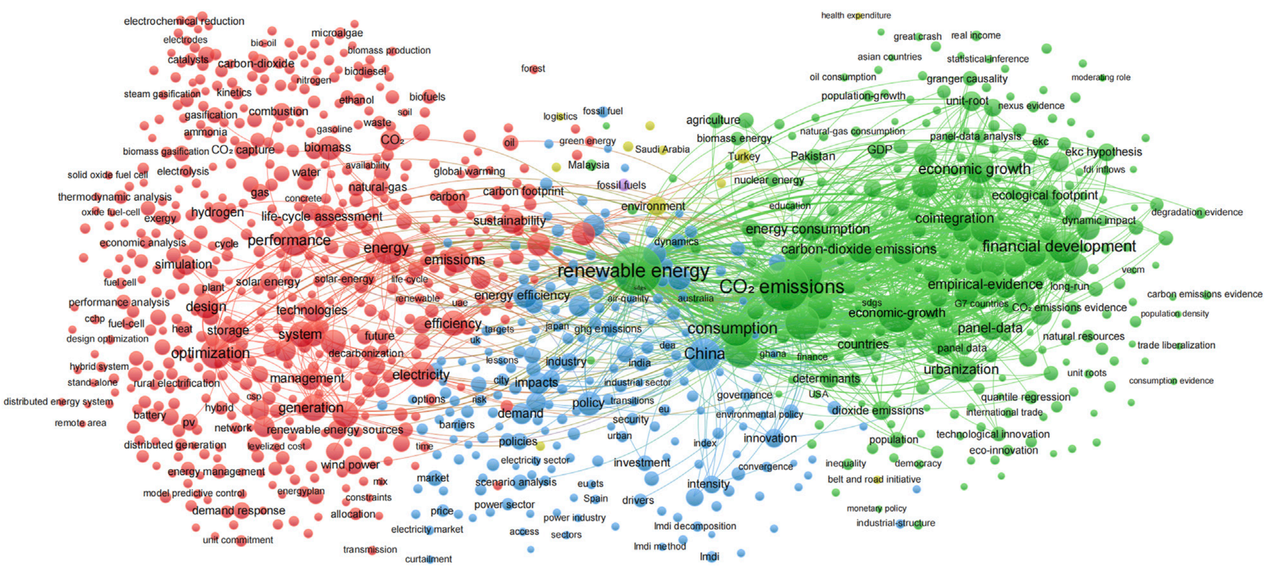

FIGURE 5
The occurrence network map of keywords.

as the predominant keyword, occurring 2,101 times, thus constituting 16.53% of all publications. Following closely is "CO_2 emissions," occupying the second-largest proportion of space at 9.23%. These two keywords collectively represented the most substantial proportion of the total number of articles, each occurring more than 1,000 times. "Economic growth," "carbon

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emissions," and "energy consumption" constitute the second tier of keywords, each appearing more than 500 times in the corpus. The remaining keywords within the top 20 range from 100 to 500 occurrences in the corpus.

It can be seen from Figure 4, papers prioritize themes such as "renewable energy," "CO_2 emissions," "economic growth," "carbon emissions," and "energy consumption." The economic development of most developing countries primarily relies on traditional fossil fuels (Liu et al., 2022; Raza and Dongsheng, 2023). As the global population continues to grow, the demand for resources also increases. However, the stock of traditional fossil fuels is insufficient to meet the current population scale. Therefore, the pursuit of "renewable energy" as an alternative to traditional energy sources can effectively address the issue of energy scarcity. Hence, the prevalence of "renewable energy" in existing literature in this field is understandable. In addition, economic growth typically corresponds to heightened energy consumption, and leading to environmental degradation in turn. Among the indicators monitoring environmental impacts, carbon emissions occupy a focal point. Consequently, "economic growth," "energy consumption," and "carbon emissions" are also keywords with high frequencies in this context.

We also explored the co-occurrence relationships high-frequency keywords during 1990–2022 (Figure 5). The nodes are high-frequency words, the size of which is proportional to the occurrence frequency. The lines represent the relational link between two words, with the thickness indicating the strength of the connection. Keywords of the same color indicate a closer association compared to keywords of different colors. As shown in Figure 5, network visualization of the terms in keywords related publications showed three distinct clusters representing different major research themes. The blue and red cluster were the largest cluster. In general, "renewable energy" emerges as the most frequently occurring keyword and occupies a central position within the keyword co-occurrence graph. Additionally, within the realm of green keywords, "renewable energy" and "CO_2 emissions" exhibit a notably close relationship and stand out as the most prevalent terms. Among the blue-themed keywords, "China" exhibits a closer association with terms such as "policy," "energy efficiency," and "demand," emerging as the most frequently occurring keyword. In the red-themed keywords, "energy," "emissions," "system," "generation," and "optimization" are intricately interrelated, emerging as the most closely associated terms. Moreover, these keywords also stand out as the most frequently occurring within the red category.

Obviously, the topic of "CO_2 emissions" exhibits a strong correlation with both energy conservation and emission reduction as well as SDG 7. Many scholars have highlighted that the degradation of the ecological environment and the occurrence of various extreme disasters due to extensive energy consumption and CO_2 emissions will result in substantial economic losses for all countries globally. However, evaluating the extent of energy consumption and the current state of CO_2 emissions is a complex endeavor. Measurement of energy efficiency involves considerations such as energy economic efficiency and energy technical efficiency. Likewise, there are diverse approaches for assessing CO_2 emissions levels, including total emissions and intensity index (Galeotti et al., 2020). Moreover, the development and utilization of renewable energy has become an effective approach to addressing climate change and achieving the objectives of energy conservation and emission reduction. Efforts focused on energy conservation and emissions reduction for environmental protection fundamentally involve adjusting industrial structure and energy consumption patterns that impact the environment (Verma et al., 2021). Renewable and clean energy sources are considered the inevitable path for future energy development. This approach not only achieves the goals of energy conservation and emissions reduction, thereby alleviating the crisis of traditional fossil fuel scarcity, but also significantly reduces the heavy burden of environmental governance and ecological conservation resulting from economic development (Lior, 2008). The topic of "economic growth" has garnered significant attention from researchers, primarily because of the intricate relationship among the economy, energy, and the environment, which has emerged as one of the most pertinent topics not only in energy economics but also among environmental scientists and policymakers.

3.4 Country productivity and collaborations

Through international cooperation network analysis, it is possible to assess the level of international collaboration among countries in specific fields. It helps to understand whether research activities in particular fields exhibit international characteristics, as well as the extent and frequency of international collaboration. By understanding the collaboration patterns and intensity among different countries in specific fields, suitable partners can be identified, leading to the establishment of robust international collaboration networks. Figure 6 indicates that China, United States, United Kingdom, Germany, Spain, Pakistan, Turkey and Russia were the most productive countries/territories. China, United States and United Kingdom were the center of the national cooperation network. In the Figure 5, the large spheres representing these three countries may be attributed to their substantial economic scales and historically high carbon emissions over the past few decades. Consequently, they have produced the most research papers related to energy and carbon emissions. Moreover, the significant trade volumes of these countries facilitate extensive economic interactions with other nations. This economic exchange, in turn, fosters collaborative research efforts, leading to a higher number of co-authored papers in the fields of energy and carbon emissions. It elucidates why these three countries occupy central positions in the international collaboration network. China was the principal collaborator with other countries include Turkey, Russia and Uzbekistan. The United Kingdom is generally more closely associated with Germany, France, and Spain within the context of the analyzed data. The United States typically collaborates on papers with India, Australia, Japan, South Korea, and Malaysia. Saudi Arabia typically maintains closer collaborative ties with countries such as the United Arab Emirates, Iran, and Egypt.

Figure 7 depicts a Sankey diagram constructed by correlating publication timestamps, keywords, and country affiliations, facilitating a three-factor analysis. The width of each grid within the indicators indicates the magnitude of their respective values,

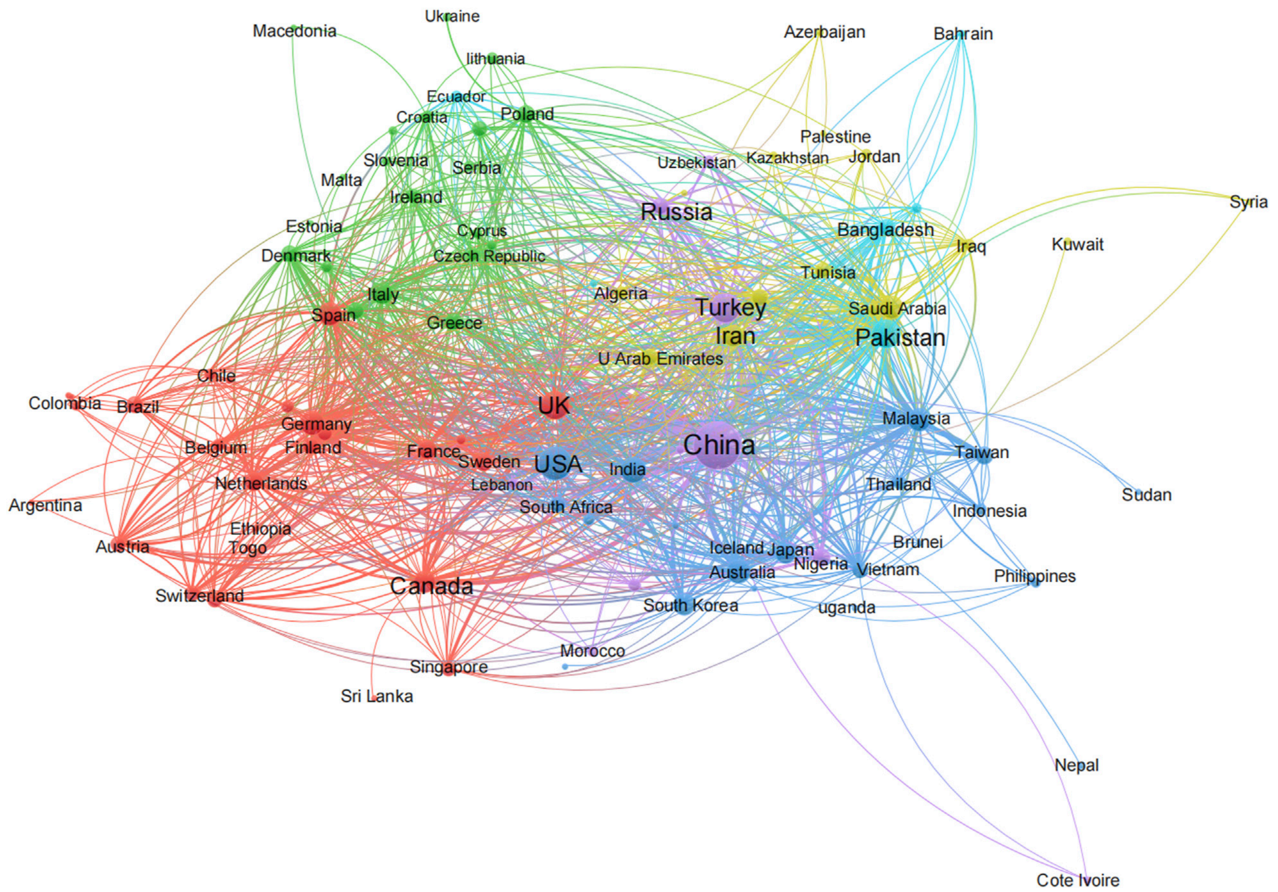

FIGURE 6
National cooperation network. Note: the size of the country name reflecting the publication volume, and the thickness of curve line representing the intensity of cooperation between the nodes.

with denser grids representing a higher number of articles published in a given year, as well as a greater number of keywords and articles published by each country. Meanwhile, the thickness of the connecting curves signifies the strength of association between the two indicators. Thicker curves imply a closer relationship between the year of publication and the keyword, as well as between the country and the keyword (Aria and Cuccurullo, 2017). This analytical approach enables a clear and intuitive visualization of prevalent keywords in a given year, thereby elucidating the research focus of a particular country. In most years, "renewable energy" consistently emerges as a primary research focus. For instance, in 2014 and 2015, research publications predominantly focused on "CO_2 emissions." However, in most years, including 2022, the majority of papers primarily center around "renewable energy." Additionally, "CO_2 emissions" and "economic growth" feature prominently as secondary and tertiary hot keywords in publications. Examining the relationship between countries and keywords reveals China as the leading contributor to publications, reflecting its heightened focus on renewable energy issues. Following China, United States and United Kingdom also prioritize research on renewable energy. In contrast, Turkey, the fourth most prolific contributor, demonstrates a distinct emphasis on "economic growth" as opposed to renewable energy.

3.5 Highly cited article

The academic influence of certain article can be seen through the number of citations it receives. The most cited papers are the most influential research results in the field, and we compiled the number of citations up to 2022 and basic information for the 20 most cited papers in Table 3. The most cited paper, authored by Lewis and Nocera in 2006, has accumulated a total of 6,582 citations, averaging 387.18 citations per year. They proposed a blueprint for reaction chemistry crucial in enabling sustainable utilization of solar energy as the primary energy source for humans. This work has effectively promoted the promotion and use of new energy, which is closely linked SDG 7.1, 7.2 and 7.3. Additionally, Panwar's article as the second most cited paper, synthesized methods aimed at reducing carbon dioxide emissions, focusing on innovations such as solar stoves, water heaters, and other relevant approaches. This article seamlessly aligns with the objectives outlined in SDG 7.2 and 7.a. Moreover, Thackeray et al (2012) contextualized lithium battery technology within a historical framework, providing insights into how this technology could address the technological challenges facing electrically powered transportation. This research is closely linked to SDG 7.2, 7.3, and 7.a.

The current study showed a steep increase in the number of SDGs-related publications with time reflecting an increasing interest of researchers in topics that are related to SDGs. The significance of

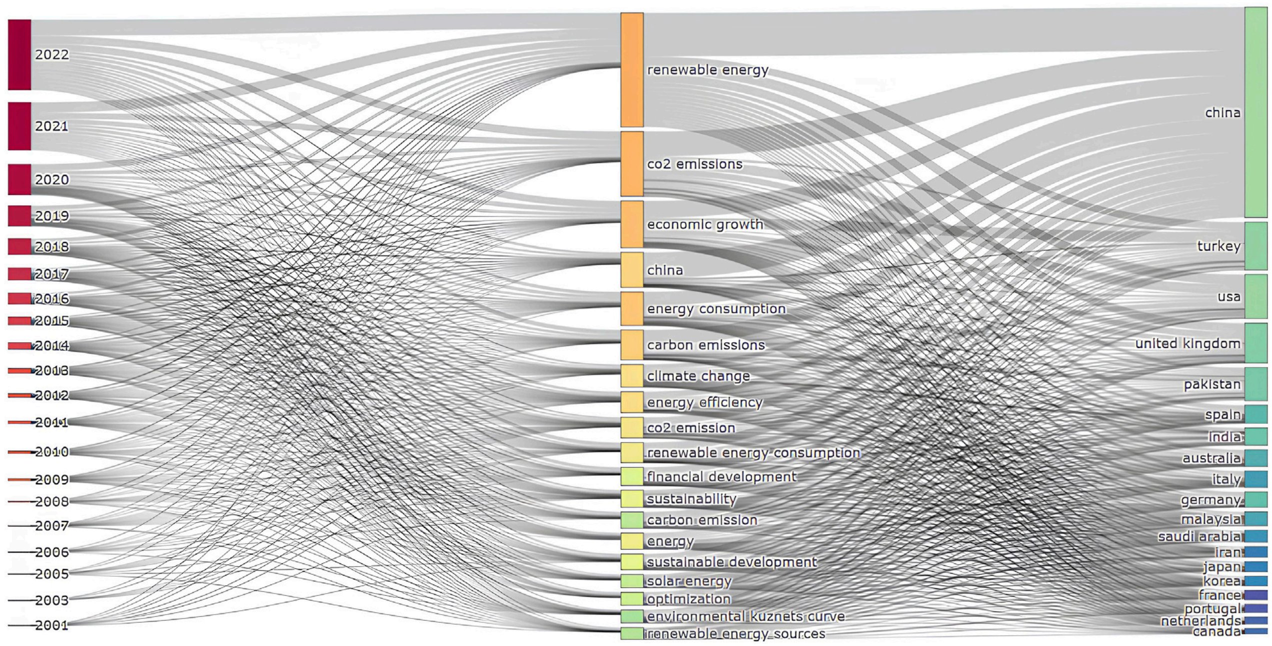

FIGURE 7
Three factor Sankey chart.

exploring the intensity of renewable energy utilization is underscored by the United Nations' SDG 7 sub-target of enhancing global energy consumption efficiency levels. Table 3 provides a compilation of the top 20 most frequently cited articles in the research field from 1990 to 2022. These articles are widely acknowledged and extensively discussed in academia. They span diverse disciplines, encompassing renewable energy, energy and environmental science, chemistry, and other related fields. Among them, renewable energy holds a prominent position in these studies, indicating sustained global interest and investment in its advancement. Furthermore, the articles are intricately linked to the subcategories of United Nations SDG 7, encompassing energy accessibility, energy efficiency, renewable energy, and etc. This emphasizes their significance in attaining sustainable energy development objectives. Nonetheless, the achievement of SDG 7 depends on individual countries' visions for their future societies and development trajectories. Each country must devise policies and measures tailored to its specific context and resource circumstances, while also considering global equity and developmental requirements during policy formulation and execution. It is crucial to ensure that all countries share responsibilities in addressing energy challenges and work towards achieving SDG 7. These highly cited papers collectively showcase the academic community's commitment to SDG 7 and offer essential theoretical underpinnings and practical insights for realizing these objectives.

3.6 Limitations and uncertainties

The limitations of this study include the following three aspects: Firstly, our study exclusively relied on the Web of Science database and did not incorporate outputs from other databases. Hence, the research findings might exhibit limitations in term of comprehensiveness and representativeness. Secondly, our keyword analysis and citation analysis concentrated solely on prominent topics and disciplines. Owing to constraints in data availability, various fields and trajectories characterized by lower citation frequencies and less frequent keyword occurrences were not examined, leading to a paucity of discourse on these less-explored yet potentially consequential domains. While these less mainstream fields may presently receive scant attention, they may harbor significant research value and prospects for future development. Subsequent investigations ought to take into account these dimensions to offer a more exhaustive and nuanced academic perspective. Finally, it is imperative to acknowledge that the findings of this study may become outdated within a relatively short span of time, thereby warranting a reassessment of the scientific community's attention towards the SDGs.

4 Conclusion

A bibliometric analysis could offer a quantitative comprehension of the existing research landscape within a specific field. This approach can augment specific research initiatives by providing valuable insights into the current state of scholarly endeavors. Based on the bibliometric methods, our study provided an in-depth analysis of energy conservation and emission reduction in support of the SDG 7, covering scientific outputs in terms of publications, subject categories, keywords analyses, national productivity and collaboration, and highly cited articles, in order to reveal its research base and evolutionary trajectory. All papers related research topic were collected from the SCIE and SSCI

TABLE 3 Top 20 most frequently cited articles, 1990–2022.

Rank	Author	Year	Country	TC	CPY	Journal	SDG7 Subcatalog
1	Lewis and Nocera (2006)	2006	United States	6,582	387.18	Proceedings of the National Academy of Sciences of the United States of America	SDG 7.1/7.2/7.3
2	Panwar et al. (2011)	2011	India	2,043	170.25	*Renewable and Sustainable Energy Reviews*	SDG 7.2/7.a
3	Thackeray et al (2012)	2012	United States	1,944	176.73	*Energy and Environmental Science*	SDG 7.2/7.3/7.a
4	Leung et al. (2014)	2014	China	1,860	206.67	*Renewable and Sustainable Energy Reviews*	SDG 7.3/7.a
5	Li et al (2011)	2011	United States	1,680	140.00	*Coordination Chemistry Reviews*	SDG 7.3/7.a
6	Gielen et al (2019)	2019	Germany	1,659	414.75	*Energy Strategy Reviews*	SDG 7.1/7.2/7.3/7.a/7.b
7	Gao et al (2016)	2016	China	1,379	197.00	*Nature*	SDG 7.1/7.2/7.3/7.a
8	Wang et al (2009)	2009	China	1,339	95.64	*Renewable and Sustainable Energy Reviews*	SDG 7.3/7.b
9	Zubi et al. (2018)	2018	Spain	1,246	249.20	*Renewable and Sustainable Energy Reviews*	SDG 7.3/7.a
10	Ma and Zhou (2010)	2010	United States	1,146	88.15	*Chemical Communications*	SDG 7.3/7.a
11	Palacín (2009)	2009	Spain	1,135	81.07	*Chemical Society Reviews*	SDG 7.1/7.2/7.a
12	Saidur et al (2011)	2011	Malaysia	1,045	87.08	*Renewable and Sustainable Energy Reviews*	SDG 7.2/7.a
13	Nejat et al. (2015)	2015	Malaysia	1,042	130.25	*Renewable and Sustainable Energy Reviews*	SDG 7.a/7.b
14	Hannan et al (2017)	2017	Malaysia	1,033	172.17	*Renewable and Sustainable Energy Reviews*	SDG 7.1/7.2/7.3/7.a
15	Dawood et al (2020)	2020	Australia	984	328.00	*International Journal of Hydrogen Energy*	SDG 7.3/7.a
16	Goeppert et al (2014)	2014	United States	971	107.89	*Chemical Society Reviews*	SDG 7.3/7.a
17	Holmberg et al (2012)	2012	Finland	950	86.36	*Tribology International*	SDG 7.3/7.a
18	Holmberg and Erdemir (2017)	2017	Finland	909	151.50	*Friction*	SDG 7.3/7.a
19	Shahbaz et al (2013)	2013	Pakistan	839	83.90	*Renewable and Sustainable Energy Reviews*	SDG 7.b
20	Amasyali and El-Gohary (2018)	2018	United States	832	166.40	*Renewable and Sustainable Energy Reviews*	SDG 7.1/7.2/7.3

Note: TC, is the number of total citations of this article; CPY, denotes citation per year.

databases spanning 1990–2022. It was found that the number of relevant articles has increased year by year since 2009, especially in recent years, when the increment is most obvious, indicating that research in the field of SDG 7 and energy has attracted a lot of attention from the academic community. In the analysis linking countries or regions to the number of papers published, the most productive countries or regions were concentrated in the Asian and European regions. The data found that China, the United States and the United Kingdom had the most publications in this area, each accounting for 34.2%, 11.9% and 8.6% of the total publications, respectively. Among them, China is the country with the most publications, with a total of 4,626 papers, indicating that sustainable development on energy is one of the most concerned areas in China in recent years. In terms of research themes, Energy and Fuels is a hot area in the existing literature, accounting for 49.76% of the total publications, followed by Environmental Sciences, which are the hot areas of research on sustainable development so far. In the keywords analysis, "renewable energy" is the most frequently occurring keyword, and acts as the central node in the keywords network analysis. The most closely related keyword is "CO_2 emissions," which emphasizes the concern about CO_2 emissions in the field of renewable energy, followed closely by "economic growth," which highlights the importance of economics in the study of CO_2 emissions. This study also analyzes the cooperation among different countries on the research of energy conservation and emission reduction in support of the SDGs, and the results showed that China, the United States and the United Kingdom, as the major research countries, have cooperated more frequently in this field, making important contributions to promoting global energy sustainable development. According to the literature citation analysis, the sharp increase in the number of publications reflects the growing interest of researchers in the issue of energy efficiency and emission reduction under SDG 7. Notably, literature related to renewable energy sources ranked high in the number of citations, followed by research involving chemical technologies to improve energy efficiency. As the global demand for renewable energy continues to grow, research efforts aimed at achieving more efficient energy utilization and reduce adverse environmental impacts become critical. This paper reveals research trends in the field of sustainable development and energy conservation and emission reduction, provides research references for researchers in the field, and can assist policymakers in formulating policies and development goals related to energy exploration and utilization.

Data availability statement

The original contributions presented in the study are included in the Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

KX: Conceptualization, Methodology, Writing–original draft. MY: Conceptualization, Methodology, Writing–original draft. JY: Data curation, Resources, Writing–original draft. BN: Data curation, Writing–original draft. YC: Data curation, Writing–original draft. HZ: Data curation, Writing–original draft. YW: Conceptualization, Methodology, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This work was supported by the National Social Science Fund (No. 23FGLB073), the Hubei Provincial Natural Science Foundation (No. 2022CFB769) and the Project of Philosophy and Social Science Research of Hubei Provincial Education Department (No. 21G010).

Conflict of interest

Author JY was employed by Changjiang Engineering Supervision Consulting Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2024.1421990/full#supplementary-material

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