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## Article

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Research in Globalization

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Elsevier

*Suggested Citation:* Tao, Zhibin; Chao, Jiaxiao (2023) : A bibliometric and visualized analysis of research on green finance and energy in a global perspective, Research in Globalization, ISSN 2590-051X, Elsevier, Amsterdam, Vol. 7, pp. 1-20, <https://doi.org/10.1016/j.resglo.2023.100156>

This Version is available at:

<https://hdl.handle.net/10419/331084>

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# A bibliometric and visualized analysis of research on green finance and energy in a global perspective

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## ARTICLE INFO

### Keywords:

Bibliometric  
Green finance  
Energy  
Research hotspots

## ABSTRACT

In order to explore the current status and progress trend of global research in the field of green finance and energy, this paper is based on 162 literature information of research in this field published from 1 January 2000 to 31 December 2022 in the Web of Science Core Collection, using bibliometric methods and CiteSpace and VOSviewer software to analyze the number of publications, citation frequency, authors, journals, keywords and countries, etc., so as to analyze the global research progress in this field during this period. The results illustrate that the number of literature publications in this field has grown dramatically since 2021. The literature in the WOS database involves 48 countries around the world, among which China has the largest number of publications, accounting for 75.31% of the total number of publications, and Japanese scholars have the highest average number of citations for their articles, at 57.21. “Environmental science and pollution research” and “Renewable energy” are the main journal carriers of the literature in this field. High-frequency keywords for instance “green finance”, “economic-growth”, “renewable energy”, “CO<sub>2</sub> emissions”, and “consumption” constitute the representative terms in this field and are the core content of the research in this field. Exploring the link between green finance and carbon dioxide emissions intensity, climate finance and renewable energy are the core objectives of investigation in this field. At present, there is a paucity of literature that systematically explores the intrinsic links between green finance and the energy field, so we have filled the relevant research gaps to some extent. The results analyzed by a bibliometric method are helpful to comprehensive understand the current status, progress and foresight of this field, and to provide reference for future studies. Furthermore, we identified key themes in this research area, finally, provide the following policy recommendations: (1) Integrated planning, cooperation, and global transformation for green finance (2) Research, diversify finance, and support for green energy progress (3) Collaboration for sustainable development and environmental responsibility.

## Introduction

The ongoing worldwide COVID-19 pandemic has generated an unprecedented global economic and public health emergency (Hoang et al., 2021), which in addition to posing a serious threat to the lives and health of millions of people worldwide (Sharma, Kraus, Srivastava, Chopra, & Kallmuenzer, 2022), the global energy and ecological environment has also been severely frustrated and struck (Priya, Cuce, & Sudhakar, 2021). Despite the large number of energy policies that confirm a blueprint for the future development of renewable energy, COVID-19 has had a huge impact on the energy sector globally, posing significant challenges and uncertainties for the energy transition, (Tian,

Yu, Xue, Zhuang, & Shan, 2022; Zhang et al., 2021), and has a high potential to hinder the deployment and efficiency of new renewable energy projects in practice (Hoang et al., 2021). There is intense global debate on the progress of driving the global energy transition in the post-epidemic era, and expressed concern about the overemphasis on economic recovery (Sun et al., 2019; Tian, Yu, Xue, Zhuang, & Shan, 2022). In addition, the sharp decline in global demand caused by the epidemic led to a sharp fall in energy prices, resulting in market distortions (Hoang et al., 2021). The control of oil producing countries over energy markets has also been weakened (Guan et al., 2020), with energy, transport and raw materials reaching their lowest levels (Priya, Cuce, & Sudhakar, 2021), and the resulting plunge in oil prices has further

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hindered the use of cheap oil for renewable energy development, with the competitive advantage of renewables over conventional energy sources (Tian, Yu, Xue, Zhuang, & Shan, 2022).

In addition to the impact of the COVID-19 pandemic, the global energy system is currently undergoing a transformative shift driven by factors such as technological innovation, climate change, and geopolitical crises (Singh, Bocca, Gomez, Dahlke, & Bazilian, 2019). Energy transitions encompass assumptions of energy efficiency, affordability, reliability, and energy independence (Cantarero, 2020). Beyond the technological aspect, the current energy transition also involves social-economic (Singh et al., 2019), ecological and climate (Gralla, Abson, Møller, Lang, & von Wehrden, 2017; Bogdanov et al., 2021), geopolitical and national security (Singh et al., 2019), as well as inequality and poverty issues (Jasanoff, 2018; Jenkins, Sovacool, & McCauley, 2018). As a result, it has become an interdisciplinary research theme.

Environmental issues seem to have become a major strategic issue for most industries since the beginning of the 21st century (Quazi, 2001). Rapid economic growth has also brought with it serious problems of ecological degradation and even public health risks (Wang, Liao, & Li, 2021). Therefore, environmental governance is closely linked to our level of living and health as well as to sustainable economic and social development (Ruan, Qiu, Chen, Liu, & Ma, 2022). Furthermore, pollution is a manifestation of 'external diseconomy' as a result of a series of measures taken by a large number of industrialised enterprises to maximise profits (Shi, Jiang, Bao, Zhang, & Kang, 2023). Therefore, Quazi (2001) suggests that if we want to build a more sustainable society we must transform business and production into systems that are sustainable and resilient. Meanwhile, Howat and Stoneham (2011) encourage ensuring that population growth is stable, as it is one of the most important measures to control climate change and improve public health equity. On the other hand, Satterthwaite (2009) in his article finds that population growth is not a factor in the growth of greenhouse gas emissions, but is related to the amount and level of consumption. Therefore, scholars' research on sustainable consumption has appeared a "boom" phenomenon. Liu, Qu, Lei, and Jia (2017) collated and reviewed the relevant literature and found that research in the area of sustainable consumption no longer moves from a single practice-oriented to a diverse and interdisciplinary field that includes consumer behaviour, energy and climate change, and ecology. Vringer, Van Der Heijden, Van Soest, Vollebergh, and Dietz (2017) found through field research that consumers not only evaluate the pros and cons between personal financial costs and sustainable benefits when consuming sustainably, but also think about the consequences if they restrict the freedom of choice of others.

Our society is at a turning point in its search for further development, and the emergence of the concept of sustainability provides value to that vision (Hull, 2008). In 2015 the United Nations published a set of Sustainable Development Goals policies to guide the world's development until 2030 (Lee et al., 2016). Holden and Linnerud, (2007); Holden, Linnerud and Banister (2014); Meadowcroft (2012) argue that we cannot consider economic progress as one of the key objectives of becoming sustainable. Instead, we should meet needs, ensure equity and respect environmental requirements (Holden, Linnerud, & Banister, 2017). Therefore, we develop in a way that does not harm future generations to meet current needs (Ali, 2015).

Nowadays, governments and international organizations regard balancing economic development and environmental sustainability as key goals (Sampene, Li, Khan, Agyeman, Brenya, & Wiredu, 2022). As a link between finance and the environment, green finance is valuable in exploring the mechanisms between environmental pollution and green finance (Lei & Wang, 2020). Green finance has become a valuable strategy for social sustainability (Koondhar, Shahbaz, Memon, Ozturk, & Kong, 2021), contributing to the efficient control of greenhouse gas emissions and rapid adaptation to climate change, while financial products and services can control industrial pollution (Falcone & Sica, 2019). In addition, green finance has the role of directing the flow of

funds to resource-saving technology development and eco-environmental protection industries, as well as guiding enterprises to focus on green production and enabling consumers to develop green consumption concepts (Lin, Chen, & Qiu, 2018). Therefore, this paper believes that the study of green finance is very important.

In recent years, study on the link between green finance and energy has received more investigations from scholars. (Wang et al., 2021) found that the growth of green finance has positive influenced to the shift from traditional energy consumption to renewable energy consumption, and it has had a positive impact on the production and use of clean energy consumption in China's neighbouring provinces. (Sadiq et al., 2022) found that the development of green finance and renewable energy production can also be influenced by green bonds, greenhouse gas emission reductions. Moreover, green finance plays a pivotal role in renewable energy investments, and more specifically, green finance growth can discourage over-investment in renewable energy by cutting down bank credit issuance (He, Liu, Zhong, Wang, & Xia, 2019).

Recent studies have indicated that green finance has an indirect effect on the development of renewable energy by promoting the development of innovative technologies and increasing the openness of economic markets (Lee, Wang & Chang, 2023). Li, Dong, Taghizadeh-Hesary and Wang (2022) investigate that green economic growth and green finance are positively correlated with green energy, and that the effect on the type of green energy and its location is different. Bakry, Mallik, Nghiem, Sinha, and Vo (2023), through a study of environmental performance in developing countries, results confirm that both green finance and renewable energy have a significant dampening effect on CO2 emissions. Moreover, the issuance of green bonds lowers the threshold or criteria for people to access financial resources and the increased volume of green bonds will also reduce CO2 emissions to some extent.

On the other hand, Alharbi, Al Mamun, Boubaker and Rizvi (2023) also confirmed the significant role of green finance through a study of 44 different countries around the world, and they also concluded that the results of this study had a positive impact on controlling various demand and supply side determinants of renewable energy production. Wang, Sun, and Iqbal (2022) proposed that in E7 economies, green finance has absolute control over renewable energy innovation, i.e. the energy transition is heavily dependent on green finance performance.

Interestingly, Lee and Hussain (2023) explored the role of green finance at the household level and found that green finance at the household level can contribute to the development of a greener society and that household knowledge literacy or level of knowledge about green finance can have a stronger impact than social factors. van der Ploeg, Rezai and Reanos (2022) also suggested that a household's carbon emissions can be affected by green tax policies. And most families are considering emissions trading schemes as a new way to reduce their carbon emissions (An, Zhang, Huang, Liu, Cai & Wang, 2021).

Based on the above analysis, green finance can contribute to the energy transition and sustainable social development, it can also be found that although there are multiple perspectives on this topic in the existing literature, the research is not rich enough due to the intractability of the endogeneity in empirical studies and the spatial impact of green finance is usually neglected in the relevant studies (Lee, Wang & Chang, 2023). In addition, there is already relevant literature exploring research in the field of green finance or energy, for example Zhang, Zhang, and Managi (2019) present the latest developments and trends in green finance research and provide a reference for future research directions. Debrah, Darko, and Chan (2022) conducted a qualitative and bibliometric analysis of 995 relevant publications in the field of green finance through a mixed-methods systematic review. Regarding bibliometric studies in the energy field, Dominković, Weinand, Scheller, D'Andrea, & McKenna (2022) found that the impact of themes related to flexibility and hybrid or integrated energy systems has been greater in recent years, while individual technologies have declined. At the same time, some scholars have discussed the problem of energy poverty (Xiao,

Wu, Wang, & Mei, 2021) and the energy consumption phenomenon in households (Ma, Wang, & Li, 2019). In addition, Zhang, Liu, Han, and Liao (2022) provide a systematic review of the relationship between green finance and carbon emissions reduction. On the one hand, green finance is widely explored in the context of adaptation and mitigation of ecological degradation due to climate risks (Zhang, Liu, Han, & Liao, 2022), and it remains a relatively immature and interdisciplinary area of research (Debrah, Darko, & Chan, 2022). On the other hand, due to the global outbreak of COVID-19 and the impact of the economic crisis, there was a significant decline in continued investment in renewable energy, energy efficiency, etc. in 2020, which also led to a significant drop in oil and gas prices and hindered the growth of renewable energy projects (Sharma, Verma, Shahbaz, Gupta, & Chopra, 2022). Therefore, we believe that it is important to explore the link between global green finance and energy for the more sustainable development of society and for improving human well-being. Furthermore, regarding the existing bibliometric literature, most studies only investigate the development processes and trends in two different areas, green finance or energy, and do not explore the intrinsic links between green finance and energy, and very little literature analyses the two as a whole. Finally, relevant empirical studies on the topic have mainly focused on summarising the relationship and impact mechanisms between green finance and energy, with few systematic summaries and comparisons of the current status and trends of green finance and energy research from a global perspective. Therefore, this study fills in these gaps to some extent and also enriches the relevant research literature.

In order to investigate the global study in the field of green finance and energy, this paper uses bibliometric analysis to conduct a more comprehensive analysis of the correlative articles in this field in the Web of Science (WOS) database from 1 January 2000 to 31 December 2022, with the help of various quantitative features and visual analysis of the literature, as well as using CiteSpace and VOSviewer software to offer a focused and comprehensive summary of the research in this field, revealing the development history, investigation trends and hotspots in this field worldwide, in order to furtherance the growth of this field.

The remainder of the study is organised as follows: Section 2 describes the research methodology and presents the data sources. Findings and discussions are presented from Section 3 to Section 6, and Section 7 concludes and discusses future research directions, while also providing relevant policy recommendations.

## Methodology and data source

### Research methods

Bibliometrics first appeared in the early 20th century (Pritchard, 1969) and then formed a independent subject that has been proverbially used in the analysis of literature (Diem & Wolter, 2013). In recent years, bibliometrics has become an important tool for studying the progress of disciplines in various academic fields, using statistical and mathematical methods to study the development and status of a discipline over time (Yang & Qiu, 2018). Meanwhile, bibliometric analysis is an effective tool increasingly used in the scientific community to classify and quantitatively assess bibliographic material and literature in scientific disciplines (Lazarides, Lazaridou, & Papanas, 2023; Ellegaard, 2018). And it is possible to visualise the academic statistics of a research area by using various bibliometric tools (Li, Wu, & Wu, 2017). Bibliometrics can offer a quantitative analysis of present research and development in a field (Lyu et al., 2022), and through a systematic survey of existing research, thus revealing characteristics such as themes, authors, publications, categories, and keywords (Chen, 2004), it can objectively reflect the overall layout and hotspots of a field over time and predict its future trends, with the advantages of being comprehensive, objective, and quantitative (Zhang, Xu, & Li, 2019; Zhang, Zhang, Zhu, & Wu, 2021). It has the advantage of being comprehensive, objective and quantitative (Zhang, Xu, & Li, 2019; Zhang, Zhang, Zhu, & Wu, 2021). Abramo,

D'Angelo, and Viel (2011) suggest that the development of a field can be comprehend through bibliometric analysis to obtain performance analysis. If two papers are cited by one or more other articles at the same time, it can be considered as visual analysis, and the visualization of co-citation analysis in bibliometrics can not only help to understand the data more efficiently but also make the research results more comprehensive.

CiteSpace and VOSviewer are often used in bibliometric and visual analysis (Pan, Yan, & Hua, 2018) and are used in this paper for knowledge mapping, with CiteSpace having Timezone and Timeline functions, thus providing a clear picture of the evolution of knowledge in the temporal dimension and illustrating the historical span of documents in a cluster. And it is able to display the cited articles and the cited terms, highlighting the mapping between the research frontier and the knowledge base (Chen, 2006). VOSviewer is able to provide visualisation attempts for fields such as keywords, common institutions and authors, and has zoom, scroll and search functions which facilitate detailed look through the map (Van Eck & Waltman, 2010). Not only is it effective in avoiding coverage of important nodes when processing large-scale data, but it also emphasises the display of the main information in the dataset (Shi et al., 2021).

### Data sources

In this paper, Web of Science Core Collection was selected as the data source, because its digital literature resource database has high quality characteristics, and it is generally considered by scholars to be the most suitable database for bibliometric analysis (Ding & Yang, 2020). Sánchez, Del Río, & García (2017) propose that for more than 40 years, WoS has been the database that allows bibliometric research, while its coverage of a wide range of disciplines and complete references has kept it in widespread use. At the same time Web of Science covers a great deal of publications in different fields (Merigó & Yang, 2017) and is a major quality-oriented database that provides a more standardized record for searching relevant research literature in multidisciplinary fields worldwide (Falagas, Pitsouni, Malietzis, & Pappas, 2008). On the other hand, Web of Science (WoS) and Scopus are the two main bibliographic databases (Pranckutė, 2021). Currently, social science researchers use both Scopus and WoS databases extensively in their research (e.g. Sánchez, Del Río, & García, 2017; Cruz-Ramirez, Escalona-Reyes, Cabrera-García, & Caridad Martínez-Cepena, 2014; Ochoa Jiménez, García García, Valdez del Río, & Jacobo Hernández, 2022). For a comparison of these two databases, Franceschini, Maisano, & Mastrogiacomio (2016), by using an automated procedure to manually check for errors in a portion of the large corpus collected in both Scopus and WoS, found that while Scopus seems to be more accurate than WoS, it tends to forget to index more papers, which leads to the loss of relevant citations given or obtained, ultimately having some negative impact on the results of the bibliometric analysis. In addition, the content indexed in WoS and Scopus shows a high degree of overlap (Pranckutė, 2021), for example WoS covers 83% of Scopus citations, ranging from 68% in Humanities, Literature & Arts to 90% in Chemistry & Materials Science (Martín-Martín, Thelwall, Orduna-Malea, & Delgado López-Cózar, 2021), but studies have also found higher coverage of the humanities in WoS (e.g. Vera-Baceta, Thelwall, & Kousha, 2019; Huang et al., 2020). Equally important is the depth of coverage of literature or bibliography, especially in terms of citations, where WoS databases generally perform better (Pranckutė, 2021). However, with the rapid improvement and refinement of both databases, the scientometric community has still not come to the conclusion of which is better, and scholars' decisions about which database to use depend on their own informed decisions about what is more appropriate for a particular task (Pranckutė, 2021; Baas, Schotten, Plume, Côté, & Karimi, 2020). Finally, we found that some of the research already exists through literature searches and bibliometric analysis using the WoS database, e.g. Chen, Lin, & Zhuang (2022) provide a systematic summary of research related to wastewater treatment

and emerging pollutants for the period 1998–2021; [Gingras and Khelifaoui \(2018\)](#) assess the impact of citation dominance in the United States on science in other countries; [Markusova, Mindeli, Libkind, Zolotova, and Aкоеv \(2020\)](#) explore trends in research performance in Russia and compare it with other industrialized countries; [Ercan \(2023\)](#) provides a systematic analysis and summary of the current state of research and trends in smart tourism destinations.

**Fig. 1** a shows the data sources and selection. 248 journal papers were obtained from the search, and after data cleaning (see **Fig. 1** b), 162 valid papers were finally obtained. First, we conducted an initial literature search in the WoS database by using boolean operators and the initial review results for the keywords: TS=(“green finance”) AND TS=(“energy”), then identified the citation indexes as SCI-EXPANDED and SSCI, set the search period was set from 2000 to 01-01 to 2022–12-31 and the language was English. In 2000, the American Heritage Dictionary defined green finance as financial activities that use various financial instruments to protect the ecological environment. In the same year, China started research on green finance, and the literature on green finance first appeared in Wang’s study ([Wang, 2000](#)). As a result, this concept began to develop in the academic field, leading to discussions on the inevitability of green finance development and proposing the basic ideas for the future development of green finance. Therefore, the time span of this study can help us to explore the development process of green finance and the academic interest in the relationship between green finance and energy after the introduction of relevant policies and agreements.

This was followed by a screening of subject categories and document formats (see **Fig. 1** a for details). Next, the 248 papers collected were manually screened and reviewed to ensure that the volume of research we obtained was accurate and consistent with the research topic. Therefore, we first screened the titles and abstracts of the articles and found that there were 63 articles that did not fit the topic of the study. The full text of the articles was then read and examined, and during this process 48 articles were found to be inconsistent with the content of the research. Finally, 162 valid articles were obtained and used as sample information for the study.

## Descriptive statistics generation and description

### Basic quantitative information

The study used 162 papers from 502 authors from 301 institutions in 48 countries, published in 46 journals and citing 7479 citations from 2639 journals. The results of this analysis will be presented and discussed below.

### Information on the volume of articles issued

**Fig. 2** illustrates the distribution of papers related to green finance and energy research published over time. Overall, the amount of articles published in this area is on the rise, with no articles published from 2000 to 2012, a relative plateau from 2012 to 2020, and then no papers published from 2013 to 2017. The dramatic rise in the number of publications after 2020, reaching 105 as of 31 December 2022, is a clear indication that the field has received increasing attention and discussion from scholars in the last two years, and is increasingly becoming an emerging research hotspot in the field. The number of articles began to increase slightly in 2018 and has seen a rapid rise in the number of articles between 2020 and 2022, due to the extensive advocacy and initiatives taken by the United Nations when the Millennium Development Goals were first introduced in 2000 and later replaced the 17 UN Sustainable Development Goals in 2015 ([Shahzad, Gupta, Sharma, Rao, & Chopra, 2022](#)). The updating of the SDGs after 2015 will in some ways inevitably also lead to the concept of responsible consumption rapidly catching on as well ([Nangia, Bansal, & Thaichon, 2023](#)). At the same time, the seventh Sustainable Development Goal also focuses on

universal and efficient access to cheaper and more reliable energy, which has prompted a large number of publications in recent years ([Shahzad, Gupta, Sharma, Rao, & Chopra, 2022](#)). On the other hand, since the first green bond was issued by the European Investment Bank in 2007, the global green bond market has started to grow at a very rapid pace, with an explosion of green bonds in emerging markets, particularly in China since 2016 ([Chen & Zhao, 2021](#)).

### Bibliometric analysis of the author

Analysis of article authors not only identifies representative scholars in the field, but also provides insight into core research strengths; [Lotka \(1926\)](#) argues that a group of highly productive authors can write half of the articles in a field, and that the number of these authors is roughly the square root of the total number of authors ([Lotka, 1926](#)):

$$\sum_{m=1}^I n(x) = \sqrt{N}$$

Where  $n(x)$  is the quantities of authors who have authored  $x$  articles,  $I = n_{\max}$  is the number of articles by the most productive authors in the field (VOSviewer statistics show that  $n_{\max} = 13$ ),  $N$  is the total number of authors, and  $m$  is the minimum number of articles by core authors. On the basis of Price’s Law, the minimum number of publications by a core author in a given field is  $m = 0.749 \times \sqrt{n_{\max}} \approx 2.70$ , so authors with more than 3 publications (including 3) are classified as core authors in this field. A total of 10 core authors have published 51 articles, accounting for 31.5% of the total number of articles published, which does not reach the 50% standard proposed by Price, so, it can be considered that the field of green finance and energy has not yet emerged a relatively stable cooperative group of authors. **Table 1** depicts the top 5 most productive authors in this field.

Among the highly productive authors, Taghizadeh-Hesary has the highest number of publications, with 13 cumulative publications from 1 January 2000 to 31 December 2022, and a total of 757 citations, with an average citation count of 58.23; the remaining four authors all have a cumulative total of 5 publications, with average citations of 36.4, 81, 3.2 and 8.6. Analysis of Taghizadeh-Hesary from published papers focusing on energy consumption and renewable energy sources ([Rasoulinezhad, Taghizadeh-Hesary, & Taghizadeh-Hesary, 2020](#); [Taghizadeh-Hesary, & Yoshino, 2020](#)).

### Bibliometric analysis of the journal

In order to analyse which journal has contributed the most value to the field of study, **Table 2** shows the top 10 journals in terms of number of articles, with more than 10 articles including “Environmental science and pollution research”, “Renewable energy”, “Frontiers in environmental science” and “Sustainability”, with 24, 17, 13 and 12 articles respectively. All ten journals are part of the Open access (OA) journal, reflecting the continued development of the Open access (OA) journal to promote research in the field. Recent publications in this field in ‘Environmental science and pollution research’ have focused on the relationship between technological innovation, financial development, the digital economy, CO2 emissions, energy and environmental pollution ([Uddin, Usman, Saqib, & Makhdum, 2023](#); [Chen, Tan, & Cao, 2023](#); [Kirikkaleli, Addai, & Karmoh, 2023](#)). ‘Renewable energy’ is a journal that aims to promote and disseminate knowledge on various topics and technologies related to renewable energy systems and components, and to apply alternative energy solutions in current practice. ‘Frontiers in environmental science’ publishes a large number of research articles on the frontiers of knowledge about the natural world and its various intersections with society. An analysis of citations to journals shows that the journal with the highest average number of citations per article is “Finance research letters”, it is a journal covering all areas of finance, with five articles and 73 citations per article. It shows that the literatures

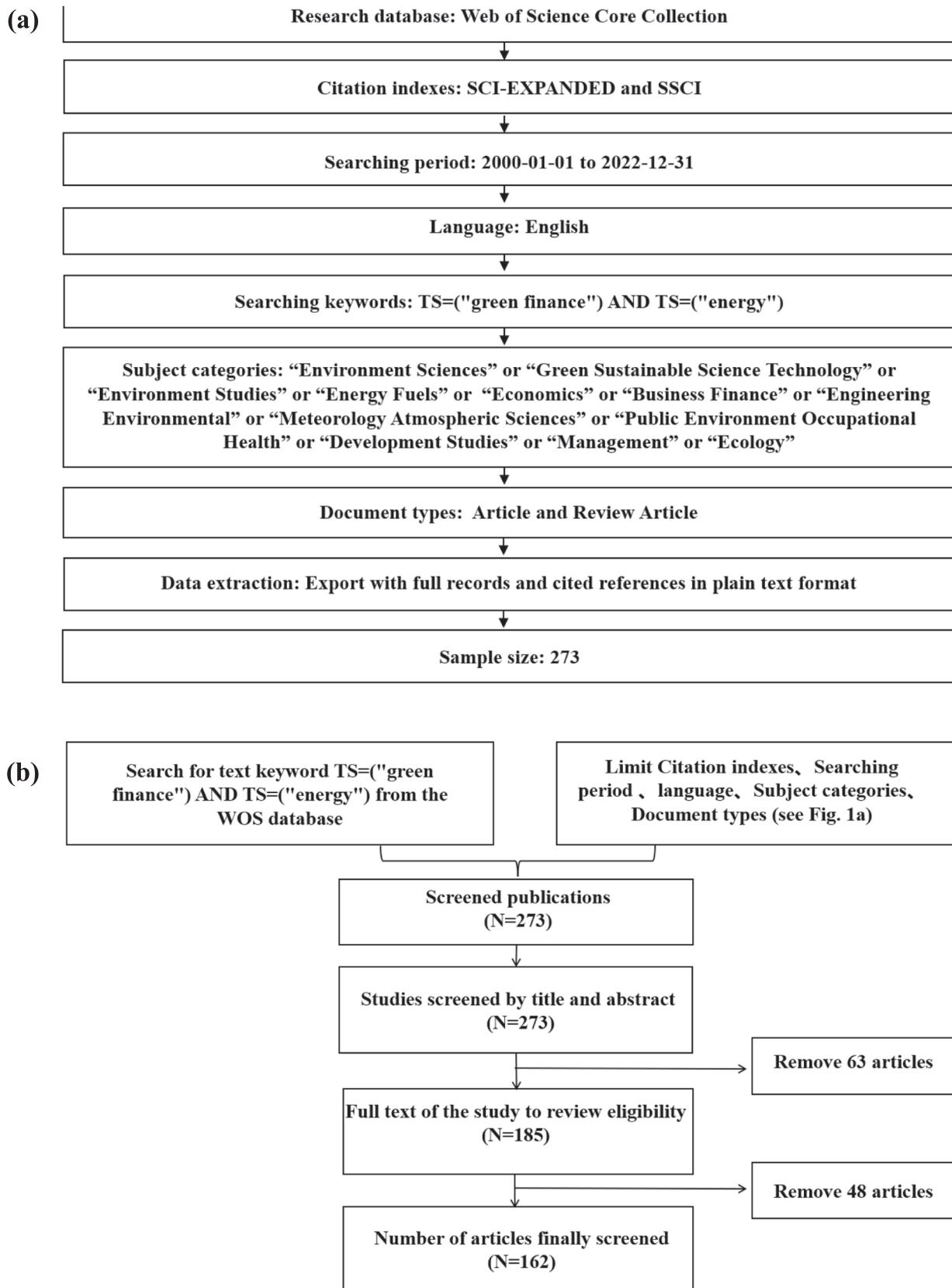


Fig. 1. (a) Summary of data source and selection (b) "Data cleaning" process.

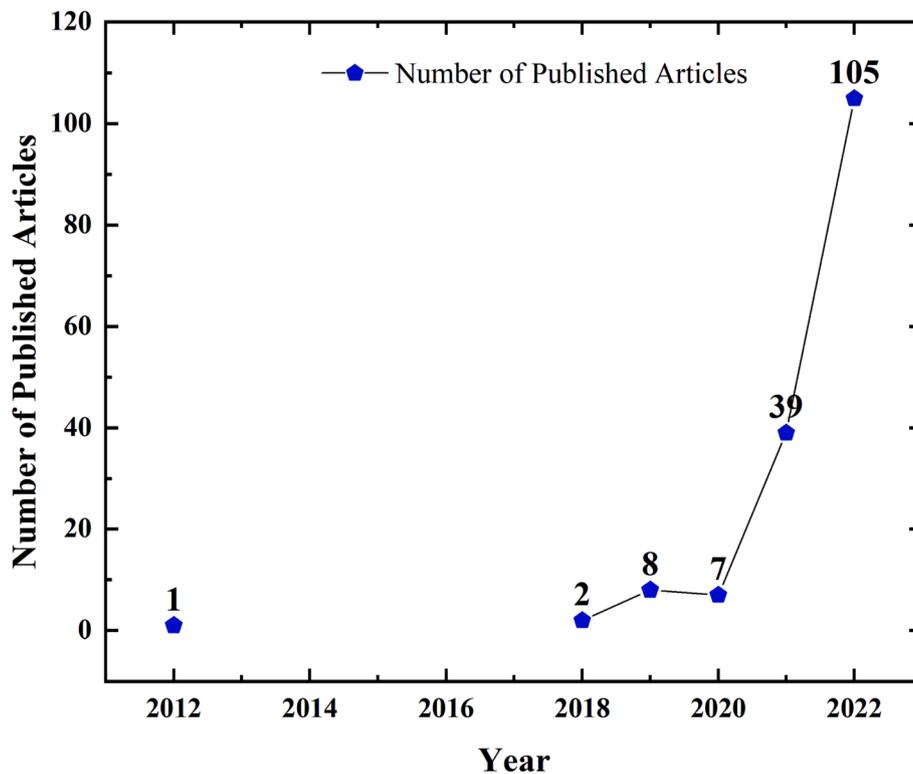


Fig. 2. Change in volume of articles issued from 2012 to 2022.

Table 1

Top 5 authors in the field of green finance and energy.

Rank	Author	Document	Citations	Average Citation
1	Taghizadeh-hesary, Farhad	13	757	58.23
2	Mohsin, Muhammad	5	182	36.4
3	Yoshnio, Naoyuki	5	405	81
4	Liu, Zhen	5	16	3.2
5	Iqbal, Wasim	5	43	8.6

Table 2

Top 10 journals in terms of publications.

Rank	Source	Document	Citations	Average Citation
1	Environmental science and pollution research	24	228	9.5
2	Renewable energy	17	140	8.24
3	Frontiers in environmental science	13	25	1.92
4	Sustainability	12	118	9.83
5	Resources policy	9	117	13
6	Economic research-ekonomska istrazivanja	8	27	3.38
7	Energy policy	7	420	60
8	Energy economics	6	159	26.5
9	Finance research letters	5	365	73
10	Global finance journal	5	126	25.2

in this journal are of excellent quality and receive a lot of attention in this field. “Finance research letters” is a collection of articles on important and new research in all areas of finance. Recent articles published in the journal include the impact of political events on economic and financial markets (Stephens, Mehdiyan, Gherghina, & Stoica, 2023), the impact of corporate carbon behaviour on financial distress (Ding, Li, Song, Ding, & Tan, 2023), the influence of climate risk or uncertainty on global firms’ (Angelidis, Sakkas, & Spiliotopoulos, 2023)

and the joint extreme risk of energy prices (Sun, Ji, Cai, & Li, 2023).

*Bibliometric analysis of the country*

In order to cognizance the countries that have contributed most to research in this area, this paper analysed the quantities of articles for 48 countries. Firstly, countries with more than 5 publications were visualised using VOSviewer as a tool, and the results are illustrated in Fig. 3. The nodes of different colours in the graph match with different clusters, with larger nodes indicating more publications and the thickness of the line between different nodes representing the level of the connection, if the line is thicker, it means that two countries are collaborating more often on publications. The outcomes exhibit that the quantities of countries publishing in this field is low and unevenly distributed, with most articles being written by a few countries’ scholars.

The Table 3 shows the countries with top5 articles, which can analyze the countries with the most productive articles in the field. Data show that Chinese scholars have created the largest number of articles in this field, publishing 122 papers, accounting for 75.31% of the total number of documents, and the number of literature citations is also the largest. Followed by Pakistan, with a total of 24 published papers. Vietnam and Emirates and England issued the same number of articles, both 8, accounting for about 4.94% of the total number of articles. The most cited per article was Japan, with 14 articles receiving 801 citations and an average of 57.21 citations per article. An analysis of the literature shows that the most recent publications by Chinese scholars in this area focus on analysing the dynamic spillover effects between green bonds, renewable energy and carbon markets (Zhang & Umair, 2023), exploring how the energy mix plays a role in the impact of green finance on environmental pollution (Wang, Wang, Cheng, & Wang, 2023), and exploring the spatial impact of national energy transitions and trade openness on CO2 emissions (Ashraf, Ashraf, & Javed, 2023), etc. Among the articles that have been widely cited and referenced by other scholars are the impact of financing constraints on driving green innovation (Yu,

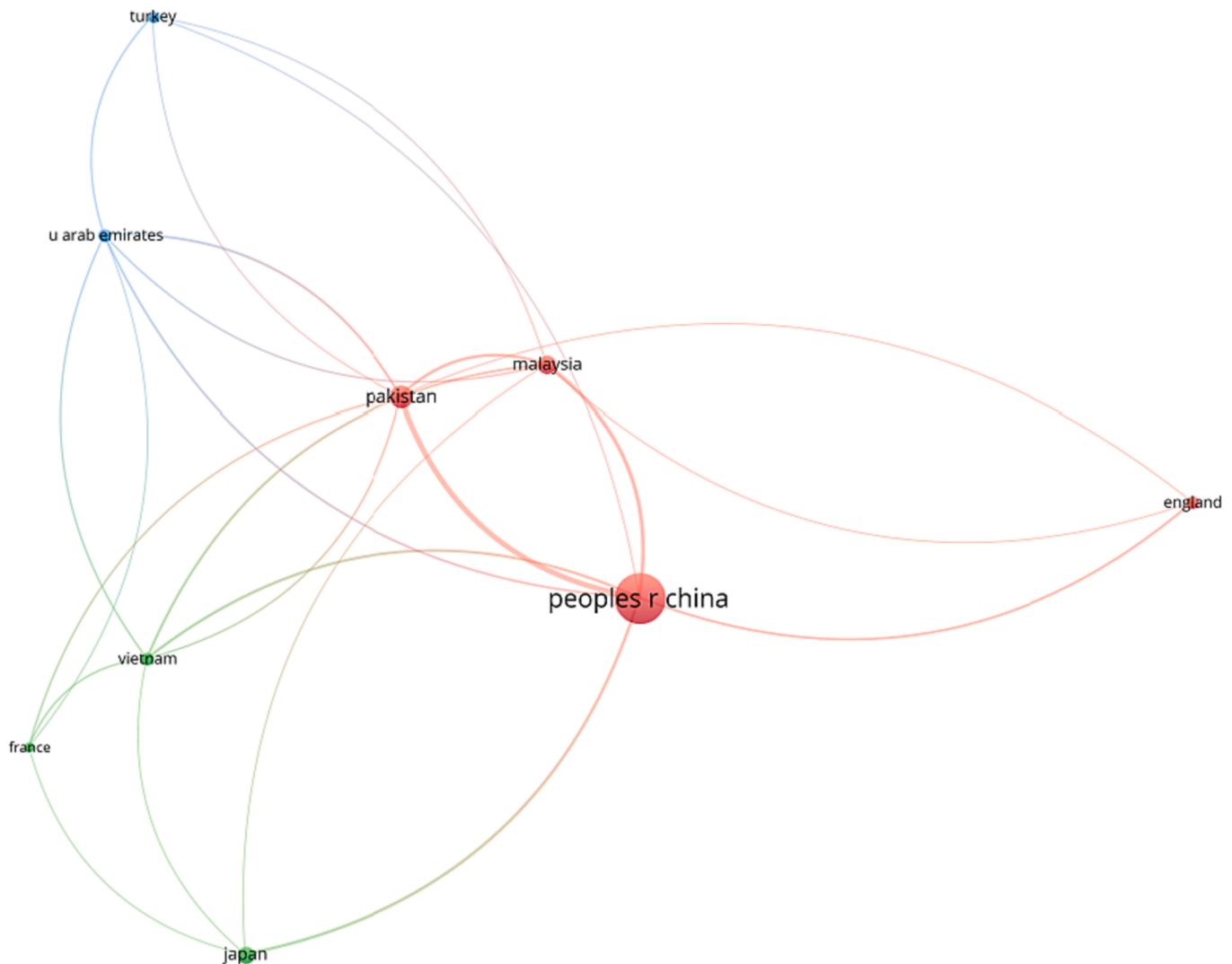


Fig. 3. Distribution of countries with more than 5 articles.

**Table 3**  
Top 5 countries with the most published articles.

Rank	Country	Document	Citations	Average Citation
1	China	122	1498	12.28
2	Pakistan	24	208	8.67
3	Malaysia	16	351	21.94
4	Japan	14	801	57.21
5	Vietnam	8	211	26.38
5	Emirates	8	194	24.25
5	England	8	158	19.75

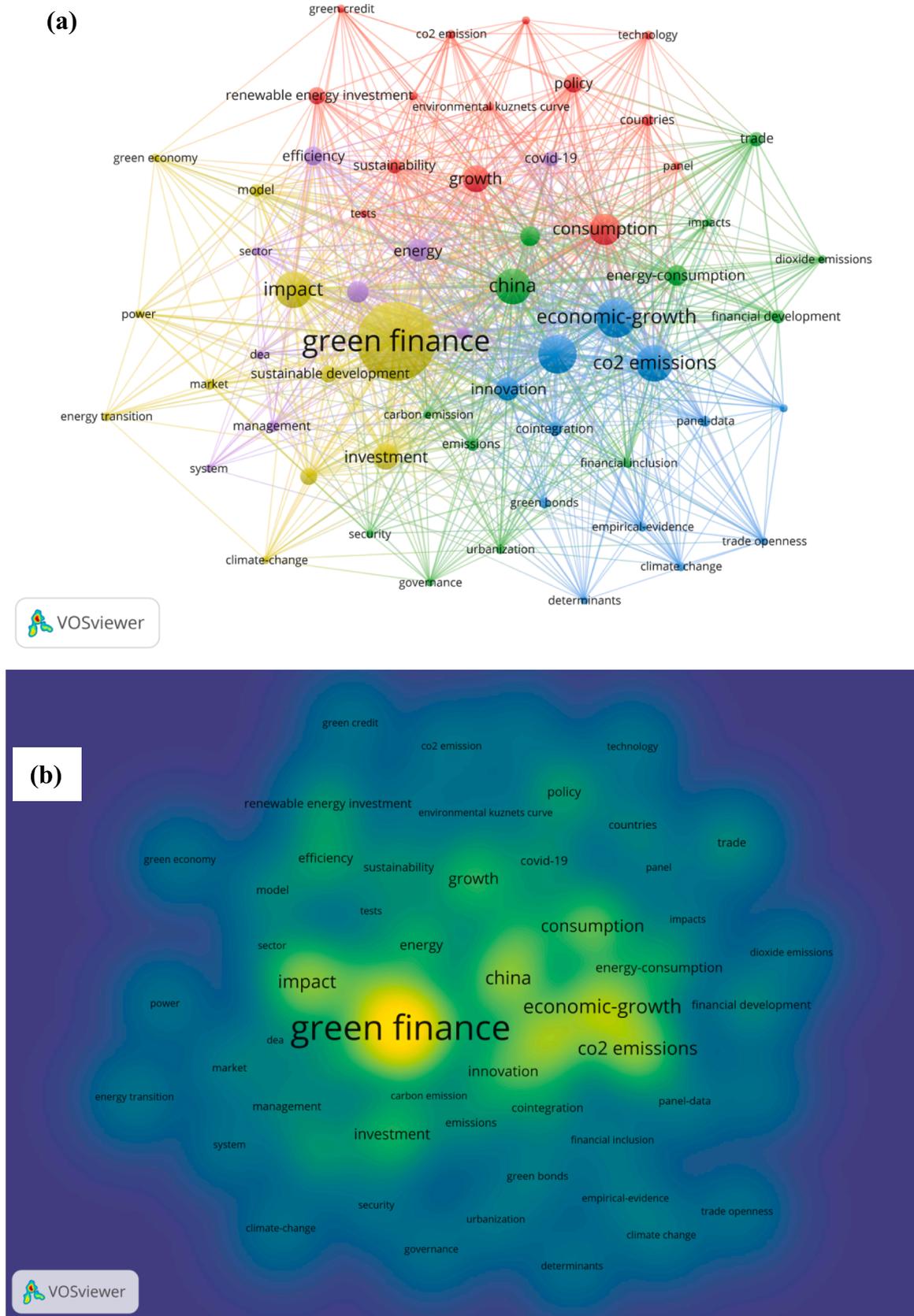
Wu, Zhang, Chen, & Zhao, 2021) ; the impact of green finance on green total factor productivity (Lee & Lee, 2022). Meanwhile, Du and Li's (2019) exploration of the impact of green technology innovations on carbon productivity has been confirmed by a large number of scholars, showing the importance of developing and adopting green technology innovations, and that green technology innovations can only impact high-income economies, so the authors encourage efficient global collaboration on green technologies. We have also investigated the drivers of the volume of publications in different countries. For China, the country with the highest number of publications, the use of renewable energy has increased from 0.03 EJ in 2000 to 7.79 EJ in 2020, and China has become the largest user of renewable energy in 2020 (Lee, Wang, & Chang, 2023). On the other hand, China is working with the

G20 to develop common standards for green finance, to explore ways to accelerate the green transformation of the global economy through green finance, and to promote global cooperation on green finance, and has attracted a great deal of attention and research from scholars as the Chinese government has introduced a number of policy frameworks for the financial system and programmes for green or renewable energy transition. In addition to this, the Intergovernmental Panel on Climate Change has stated that we need to take action on the global climate to minimise the risks and hazards of climate change and resource scarcity (Madaleno, Dogan, & Taskin, 2022). COVID-19 makes it more difficult to find funding for clean energy and support green technology development, so green financing becomes even more important (Tu, Mo, Liu, Gong, & Fan, 2021). Thus, in this context, scholars in different countries have also begun to conduct relevant research (e.g. Madaleno, Dogan, & Taskin, 2022; Sun, Yin, & Bilal, 2023; Wang, Sun, & Iqbal, 2022; Sun, Tariq, Youn, & Mansoor, 2022).

**Keywords analysis**

*Keywords co-present network view*

Keywords are a significant part of an academic paper, bringing together the core content of the paper. If you want to explore the hot-topics of investigation in a scientific field you can use keyword co-occurrence analysis. This paper applies VOSviewer to plot the



**Fig. 4.** Keyword co-occurrence map in research in the field of green finance and energy (2000–2022). The size of each node indicates the frequency of the keyword, while the node label shows the keyword. The co-occurrence link between two keywords is represented by the link connecting the two nodes. (a) Visualisation of co-occurrence keyword network. (b) Keyword density visualisation. The density visualisation system uses colours to indicate the density of each keyword. Green express a lower frequency of occurrence, while yellow indicates a higher frequency of occurrence. (c) Keyword clustering analysis.

CiteSpace, v. 5.10.R6 (64-bit) Basic  
 December 27, 2022 at 11:53:21 AM CST  
 WoS: C:\Users\29363\Desktop\Research\source\data  
 Timespan: 2012-2022 (Slice Length=1)  
 Selection Criteria: g-index (m=25), LRF=3.0, LBY=5, e=1.0  
 Network: N=218, E=445 (Density=0.0188)  
 Largest CC: 208 (95%)  
 Nodes Labeled: 1.0%  
 Pruning: Pathfinder  
 Modularity Q=0.7633  
 Weighted Mean Silhouette S=0.9422  
 Harmonic Mean(Q, S)=0.8434

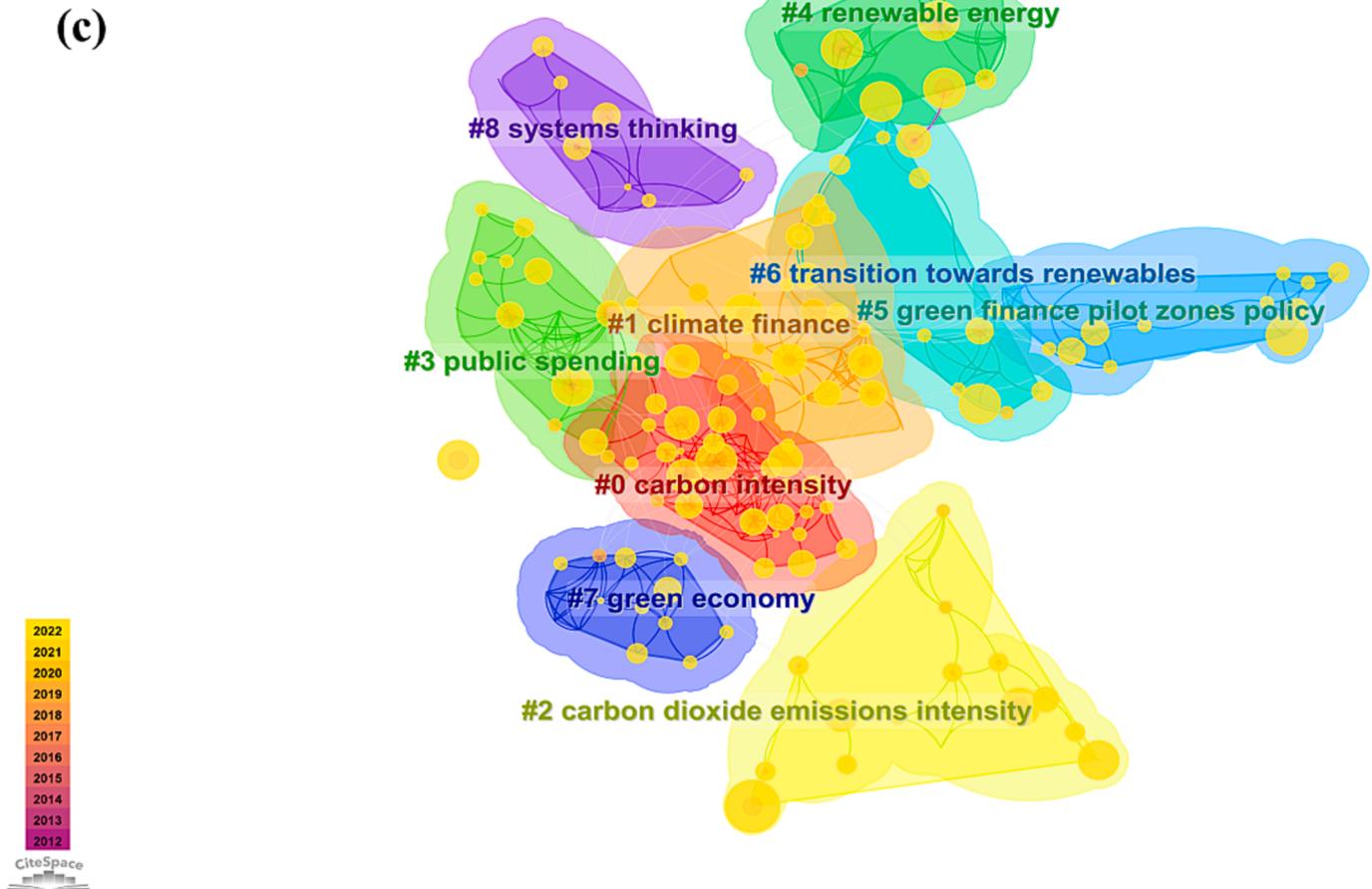


Fig. 4. (continued).

keyword co-occurrence network chart for 162 articles, where Fig. 4 a and b select 59 keywords with a frequency more than or equal to 5 for visualisation. Fig. 4 a shows the visualisation of the keyword network, Fig. 4 b shows the visual analysis of keyword density, and Fig. 4 c shows the clustering relationship of keywords.

In Fig. 4 a, the larger the circle node, the more frequent the keyword emerges and the more express of the field hotspot; the node linkage shows the strength of association, with the thickness of the linkage proportional to the frequency of both appearing together in the same piece of literature; the node colour represents different clusters and research themes. For the sake of get a clearer chart of the keywords, the high-frequency keywords with a frequency of more than 30 were made into Table 5. From Fig. 4 and Table 4, it can be known that high-frequency keywords for instance green finance, economic-growth,

Table 4  
 Keywords with a frequency of over 30.

Keyword	Occurrences	Total link strength
Green finance	104	416
Economic-growth	41	254
Renewable energy	40	201
CO2 emissions	37	236
Impact	37	187
China	36	196
Consumption	30	182

renewable energy, CO2 emissions, consumption, investment and innovation compose the representative terms in this field. The majority of keywords appear in 2021 to 2022. Among the 59 keywords with the most occurrence, only one appeared more than or equal to 100 times, 7 appeared more than or equal to 30 times, 10 appeared more than or equal to 10 times, and 35 appeared occurrences more than or equal to 5 times.

Fig. 4 b shows the description of the density of keywords. According to the application intensity of the keyword, the closer the color is to yellow, the bigger the density, the more frequently the keyword appears. Density visualization can express the overall organizational structure of the research in this field. We put the density of the key keywords in Figure b, such as green finance, economic-growth, CO2 emissions, China, and impact at the central of the visualization network chart, advising that these topics may be the focus of research in the future.

The co-occurrence map of domain keywords in Figure a was clustered (see Fig. 4 c), and the clustering mode was set to "Indexing Terms". While, the extracted labels were named with the help of LogLikelihood Ratio algorithm, 13 clusters were automatically identified, and the nine most frequently used main clusters were selected. Each unit consists of labels and nodes, with different coloured units forming different clusters. As shown in Fig. 4 b, the nine clusters are shown as red (cluster 0, carbon intensity), orange (cluster 1, climate finance), yellow (cluster 2, carbon dioxide emissions intensity), cyan (cluster 3, public spending), green (cluster 4, renewable energy), sky blue (cluster 5, green finance

pilot zones policy), sea blue (cluster 6, transition towards renewables), dark blue (cluster 7, green economy) and purple (cluster 8, systems thinking). The largest cluster is “carbon dioxide emissions intensity” and the smallest cluster is “green economy”.

#### Cluster analysis

There are different definitions of green finance, with Labatt and White (2002) argue that green finance is a form of combining economic efficiency with the concept of environmental protection and Li, Wu, Zhang, & Lin (2021) suggest that it is an umbrella term for all investment and financing practices that offer services for the environment amelioration, ecological construction, and sustainable growth. Green finance has received a large number of scholars' interest because it not only strengthens social responsibility in the region, but also promotes energy efficiency and sustainable economic development (Soundarrajan & Vivek, 2016) and the creation of carbon trading markets and socially responsible investment have become pivotal ways to boost environmental protection and economic growth (Fischer, 2017).

Research on the link between green finance and carbon dioxide emissions intensity has received various contributions from scholars. Li and Fan (2022) found empirically that the amelioration the level of green finance would control the intensity of carbon emissions, with the effect raising over time and varying by area. The influence of reducing carbon intensity is dynamic and non-linear (Gan, & Voda, 2022). Zhang and Liu (2022) find that the digital finance and green technology innovation have a pivotal affect t on local carbon efficiency, but to a certain extent inhibits the carbon efficiency of surrounding cities. At the same time, green credit is seen as an momentous way to advance China's transition to a low-carbon economy, with a signal-forming mechanism for its impact on carbon emissions, and mainly acting on two pathways: industrial structure and energy intensity (Hu & Zheng, 2022).

Studies on the climate finance. Climate finance is a distinctive form of international aid that aims to boost green economy growth and reduce CO2 emissions (Lee, Li, Yu, & Zhao, 2022). Climate finance comes from a wide range of sources and can be divided into adaptation finance and mitigation finance depending on the objective of the finance (Zhao, Zhou, & Li, 2022). Lee, Li, Yu, and Zhao, (2022) find that Climate finance can curb carbon emissions and has a smaller effect on adaptation finance than mitigation finance. Meanwhile, Bhandary, Gallagher, and Zhang (2021) argue that the criteria used can influence the outcome of climate finance policies, and that there are advantages and disadvantages to each climate finance policy. On the other hand, more countries believe that green finance has tremendous potential in addressing environmental pollution (Zhang, Chen, Tang, & Qiao, 2022). It is interesting that green bonds are vital in shaping environmentally responsible enterprises (Flammer, 2020).

GDP, investment in renewable energy and investment in R&D for environmental programs are representative of the development of green finance (Khan, Akbar, Nasim, Hedvičáková, & Bashir, 2022), and renewable energy growth is vital for energy mix transformation and environmental mitigation (Zheng, Du, & Wang, 2022). Regarding the linkage between the two, Li, Dong, Taghizadeh-Hesary, and Wang (2022) find that green economic progress and green finance are positively correlated with green energy, and that there is heterogeneity in the impact on green energy across types and regions. There is also a long-term two-way synergy between green finance and renewable energy growth (Zheng, Du, & Wang, 2022). On the other hand, Dogan, Madaleno, Taskin, and Tzeremes (2022) find that wind energy is the largest transmitter of green finance shocks, then biofuels, while fuel cells and geothermal are the minimum effect.

#### Analysis of keyword co-occurrence timezone and timeline picture based on citespace

The keywords are analysed in clusters to derive a basic picture of the

various study topics within the study area. Presenting keyword co-occurrences as a time series not only provides an insight into how the field has developed and how the frontiers have changed, but also enables the distribution of hotspots across time to be studied. In order to further analyse the keyword trends from a temporal perspective, the keyword co-occurrence chart in the field of green finance and energy interaction was displayed in the form of “timezone” through CiteSpace to obtain a timezone picture of the keywords in this field (see Fig. 5 b). The horizontal axis of the graph represents time, spanning the period 2000 to 20 December 2022, with each year as a time period and different colours representing different time periods. Citation tree rings (see Fig. 5 a) reveal the citation history of an article, and the colour of the citation ring depicts the time of the corresponding citation (Chen, 2006). Each time period matches with a vertical timeline, the keyword on the timeline depicts the first occurrence of the keyword at that time, the size of the node indicates the frequency of occurrence of the keyword, if the frequency of occurrence of the keyword is higher, the diameter of the node circle is larger. Connecting lines represent co-occurrence.

The visualisation shows that research on green finance first appeared in 2012 and did not interact with the energy sector. The node is richly connected and spans a long period of time, suggesting that this research keyword has significant academic status and research value in the field. With the increase in knowledge base, the improvement of theoretical development and the widespread interest in green finance from all walks of life, some scholars began to merge green finance with the energy sector in 2018, with the main research direction being financial growth and carbon emissions, and related discussion of financial inclusion, technological innovation and markets beginning to emerge in 2020. It is clear to see that the research keywords in this field are growing significantly from 2018 and reaching a popular period of research in 2021 to 2022, with a large number of emerging research hotspots created in 2022 as can be seen through the Citation tree rings. In general, with social development, technological progress and energy consumption, research in this field is becoming more and more integrated. The relationship between green finance and energy has also received more attention from scholars, and questions such as the link between green finance and energy and whether green finance promotes energy conservation have gradually become hot topics.

CiteSpace can use keyword co-occurrence to exhibit the changes of study topics in a research field within a certain time range, introduce time variables into the graph network, generate time eline cluster maps through the keywords after clustering, and delineate the historical trajectory and time span of the development of specific keywords in each cluster. Fig. 5 c shows the timeline knowledge map of keyword clustering obtained using the Timeline View function of Cite Space with the year of citation publication as the X-axis and the cluster number as the Y-axis.

In order to further explore the history of discuss of the link between green finance and energy and to look at future trends, the research history of the field from 2000 to 2022 can be generally divided into the following three phases based on keyword timeline mapping information. The first phase is the initial period (2012 to 2017). The quantities of publications of this order research is not large, and the number of keywords involved in the timeline map is small. Most keywords and clusters have not been produced at this stage, but the most central keywords in the field of research have emerged, such as “green finance”. The second phase is the development period (2017 to 2020). Compared with the previous stage, the quantities of publications in this stage has increased considerably, the number of keywords and clusters involved increases, and the categories are complete. Most of the keywords with high word frequency have appeared in this stage. The main keywords include “renewable energy”, “energy efficiency”, “investment”, “co2 emission”, “economic growth”, “consumption”, and so on. As green finance improves the environment and promotes economic growth (Soundarrajan & Vivek, 2016), it has a active influence on reduction of carbon intensity as the green finance development index increases (Ren, Shao, & Zhong,







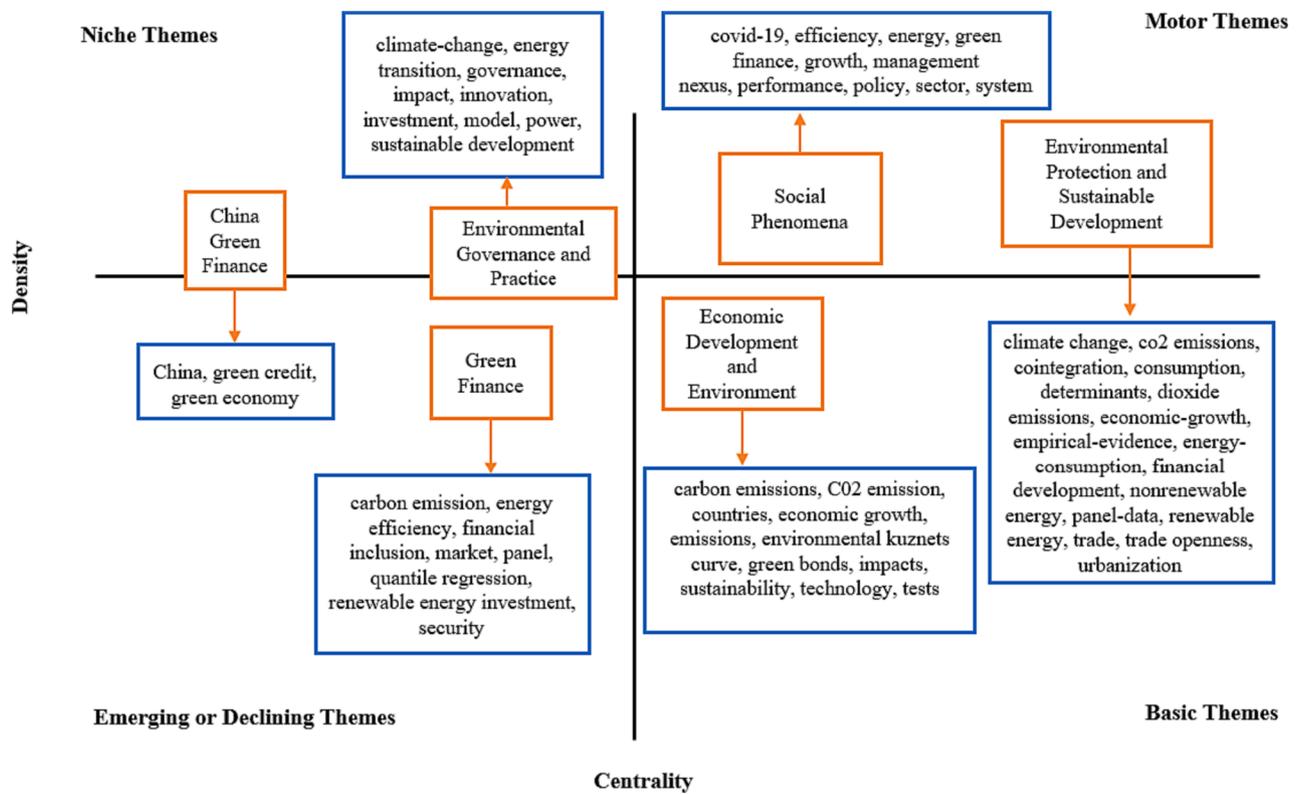


Fig. 7. Thematic map.

classifies different themes by referring to two metrics, i.e. centrality and density (Cobo et al., 2015; Aparicio, Iturralde, & Maseda, 2019). Also, the themes on the map are able to calculate the level of interaction and association between different themes through the use of Callon’s centrality, and the density is capable of expressing the internal links or strengths between keywords of the themes (Callon, Courtial, Turner, & Bauin, 1983; Aparicio, Iturralde, & Maseda, 2019). Thematic map is a matrix with four quadrants showing the research topics. The four quadrants include the motor theme, which is in the upper right quadrant and has high centrality and density; the basic theme, which is in the lower right quadrant and has low density but high centrality; the niche theme, which is in the upper left quadrant and has high density but low centrality; and the emerging or disappearing theme, which is in the lower left quadrant and has low density but high centrality. In addition, the size of the circles represents the extent to which these themes have been fully explored but need to be enriched with more relevant research (Rao, Talan, Abbas, Dev, & Taghizadeh-Hesary, 2023).

The thematic map of this research field highlights six themes, and to a certain extent these themes help us to gain a clearer, systematic and comprehensive understanding of the research process and status of a specific field (Giannakos et al., 2020). More specifically, the different thematic categories are able to convey to us some information, for example, if we want to understand the research base of a certain field of study, we can find relevant clues in Motor themes; Basic themes usually reflect the focus and core direction of research in the field, but need to be explored in greater depth and comprehensiveness; Emerging or declining themes indicate a lack or weakness of internal and external links to these corresponding themes, suggesting that even if their links with other themes become stronger in the future, more research is still needed to refine them; Niche themes illustrate that these themes have strong internal links but weaker links to major or core areas of research (Nangia, Bansal, & Thaichon, 2023; Rodríguez-Soler, Uribe-Toril, & Valenciano, 2020).

#### Motor themes

The themes that fall under this category in this study are “Environmental Protection and Sustainable Development” and “Social Phenomena”, and these two themes were the first and second ranked themes in the field respectively. “Environmental Protection and Sustainable Development” includes climate change, CO<sub>2</sub> emissions, cointegration, consumption, determinants, dioxide emissions, economic-growth, empirical-evidence, energy-consumption, financial development, nonrenewable energy, panel-data, renewable energy, trade, trade openness, urbanization (Sharma, Verma, Shahbaz, Gupta, & Chopra, 2022 ; Ji & Zhang, 2019 ; Zhang, Liu, Han, & Liao, 2022; Li et al., 2022; Zhang & Li, 2018). Currently, studies have found green finance to be an important tool or instrument for sustainable social growth, as it not only reduces greenhouse gas emissions, but also has the broad capacity to address financial products and services that cause environmental harm, and more specifically to control economic and industrial pollution, manage waste, and promote environmental protection implementation (Sharma et al., 2022). Meanwhile, Ji and Zhang (2019) suggest that the level of financial rapid development could largely determine the future development rate of China’s renewable energy sector, and Zhang, Liu, Han, and Liao (2022) argue that it could be identified as an effective incentive mechanism and provide important support and assistance for carbon reduction. On the other hand, Li et al. (2022) propose that green finance can not only have the characteristics of alleviating environmental pollution and energy consumption, but also significantly promote high-quality economic development. However, with the continuous activity of economic activities, the hindering effect of environmental pollution on economic development has become greater and greater, and the overload of economic activities poses a more serious challenge to the current social environment (Zhang & Li, 2018). “Social Phenomena” includes covid-19, efficiency, energy, green finance, growth, management nexus, performance, policy, sector, system (Priya, Cuce, & Sudhakar, 2021; Pan & Yue, 2022; Goodell & Huynh, 2020 ; Pan & Yue, 2022; Hossain, 2021 ; Priya, Cuce, & Sudhakar, 2021).

Priya, Cuce, and Sudhakar (2021); Pan and Yue (2022) suggest that the worldwide covid-19 pandemic is not only an international public health emergency, but that the major impact on global politics, energy, economy, social habits or life, ecology, labour markets, health sector and technology is also catastrophically disruptive and also to some extent impedes the normal functioning of the world's economies. Due to the uncertain and extensive economic impact, it will also have different degrees of impact on the supply chain and the financial markets. International trade and tourism are key components of supply chain networks, and there is now scholarly evidence of the impact of COVID-19 on them (Goodell & Huynh, 2020; Pan & Yue, 2022). In addition, Covid-19 has also had a significant negative impact on activities within the sharing economy, also leading to fears and worries of unemployment for many people as well as a large number of businesses not being able to function properly and falling in value or even going out of business, all of which are detrimental to people's physical and mental health, and a significant drop in energy industry when commercial buildings, offices, supermarkets, shops and markets remain closed for long periods of time (Hossain, 2021; Priya, Cuce, & Sudhakar, 2021). Therefore, in order to mitigate the multiple human hazards of global pandemics, we all need to come together to address them (Pan & Yue, 2022).

#### Base themes

The thematic map for this study shows the Base themes as "Economic Development and Environment", this theme that explores the intrinsic link between rapid economic development and environmental protection, i.e. how to correctly balance the relationship between the two. The theme reflects key words such as carbon emissions, CO<sub>2</sub> emission, countries, economic growth, emissions, environmental kuznets curve, green bonds, impacts, sustainability, technology. The rough economic development model causes huge and complex environmental pollution problems, such as increasing water pollution, air pollution, soil pollution and industrial solid waste pollution (Li, Fan, Hu, Yan, Shang, & Chen, 2022; Yi, Meng, & Li, 2022). Liang and Yang (2019) propose that environmental pollution has become one of the most serious and urgent problems in China today. Therefore, a harmonious relationship between quality economic development and friendly ecological mitigation is an important factor to guarantee sustainable development of human society (Seman et al., 2019). Li et al. (2022) also argue that as socio-economic activities become more dynamic, they also place stricter requirements on the positive relationship between energy consumption, environmental protection and economic levels. Furthermore, the link between green finance and the quality development of the Chinese economy is inevitably becoming stronger under the new normal (Gao et al., 2023). Li et al. (2022) demonstrate that green finance can provide strong support for high levels of economic development and can also mitigate environmental pollution and reduce energy consumption.

#### Niche themes and emerging or declining themes

The themes of "Environmental Governance and Practice" and "China Green Finance" are also important in this field of study, both of which are part of Niche Themes and Emerging or Declining Themes. The theme "Environmental Governance and Practice" includes keywords such as climate-change, energy transition, governance, impact, innovation, investment, model, power, sustainable development. Environmental awareness and behaviour has kept relevant environmental sociologists and researchers busy, and they have explored and analysed the field more systematically, an issue that covers a wide range of issues, from people's habits and ways of living that affect climate change in their daily lives to biodiversity and renewable energy (Spaargaren, 2011). Brown (2002) refers to a range of approaches and measures that need to be taken by different organisations in order to conserve natural resources more efficiently, maintain biodiversity and promote a sustainable level of development in society. In Spaargaren's (2011) research, he

argues that in order to make the world more sustainable we should replace the traditional consumption model - the sustainable consumption model - with a more innovative and practical approach, which can be defined as the result of a practical innovation used in different areas of personal consumption. Furthermore, in the global context of more sustainable and greener consumption, technological and cultural innovations have proven to be important forces in providing a paradigm shift in consumption (Oosterveer, Guivant, & Spaargaren, 2007). The keywords covered in "China Green Finance" are China, green credit, green economy. Green growth has been proposed by scholars in the context of sustainable economic growth, defined as a concept that aims to emphasise coordinated economic and social development, improve social welfare, and effectively address issues such as unbalanced resource allocation and environmental threats (Hao, Umar, Khan, & Ali, 2021). China, the world's largest developing economy, has made impressive progress and very impressive achievements since the beginning of its reform and opening up (Lee, Lee, & Xiao, 2021). However, the accelerated industrialisation and economic activity, as well as the abundance of energy and natural resources, have contributed to the deterioration of China's ecological problems (Lee & Lee, 2022). Therefore, China needs to deal efficiently with environmental and climate degradation without sacrificing economic development and needs to shift to an environmentally friendly development model that positively balances the harmony between the economy and the ecological environment (Zhang, Wang, Li, Si, & Liu, 2023). In this context the definition of green economic development and green finance and related policies are proposed. Meanwhile Wang, Li, Wen, and Nie (2021) proposed that green finance could be a very valuable factor in driving the green transformation of cities, and that the concept is popular not only in developing countries but also in developed countries. The value of green finance has also been demonstrated in the literature, for example, Yu, Wu, Zhang, Chen, and Zhao (2021) explored the impact of financing constraints on the level of green innovation using data on Chinese listed companies from 2001 to 2017, and found that green finance-related policies were effective in alleviating financing constraints on green innovation in general, while firms affected by financing constraints generally had relatively higher levels of innovation. In addition, Zhao, Taghizadeh-Hesary, Dong, and Dong (2023) conducted an empirical study by using CO<sub>2</sub> emissions from China's provincial panel data from 2004 to 2018 and found that green finance can contribute to carbon emission reduction and that green growth in China can not only directly mitigate the greenhouse effect but also indirectly control CO<sub>2</sub> emissions by promoting the level of green finance development.

The theme in the Emerging or Declining Themes quadrant is "Green Finance", which includes keywords such as carbon emission, energy efficiency, financial inclusion, market, panel, quantile regression, renewable energy investment, security. To address global climate degradation, ongoing ecological risks and to achieve environmentally inclusive and coherent development globally, many countries and organisations have begun to develop and optimise their green economy systems (Lee & Lee, 2022). In this background, the international financial community agrees that green finance can improve environmental quality and enhance the economy (Scholtens & Dam, 2007). The positive impact of green finance on climate change has also been confirmed by studies such as Nawaz et al. (2021), which found that carbon emissions, foreign direct investment, technology cooperation grants, research and development (R&D), and investment in private partnerships all contribute significantly to the promotion of green finance and climate change mitigation, using the Difference in Differences approach for Next-11 and within BRICS economies from 2005 to 2019. R&D and investments in private partnerships can all provide very strong support for promoting green financing and climate change mitigation. In addition, there is also some literature that explores the impact of financing constraints on environmental innovation (e.g. Ghisetti, Mazzanti, Mancinelli, & Zoli, 2015; Johnson & Lybecker, 2012; Noailly & Smeets, 2016).

## Conclusion and discussion

### Summary of research

The current definition of green finance is broad, [Sharma, Verma, Shahbaz, Gupta, and Chopra \(2022\)](#) believe it as a new model that combines sustainable business activities with the rapid economic progress. Specifically, green finance financing projects aim to improve the green inclusiveness of society, promote environmental responsibility, and adapt to climate change ([Noh, 2019](#)). Meanwhile, green finance can provide fund for green energy projects and promote the rapid development of the industry ([Pata, Yilanci, Zhang, & Shah, 2022](#)). The growth of green finance on the structure of energy and has received a large number of interest and discussion from scholars around the world and is extremely sensitive to changes in society, making it an area of research that is constantly being selected and updated. This study analyzed the relevant research and development processes in the field of green finance and energy from 2000 to 2022, and summarized the authors, countries, journals and keywords in the research field. Based on the bibliometric analysis, the conclusions of this study are drawn as follows:

- (1) The core journals for publishing papers in this filed are “Environmental science and pollution research”, “Renewable energy”, “Frontiers in environmental science” and “Sustainability”. And we found that the top 10 journals are all part of open access (OA) journals, reflecting the continued development of open access (OA) journals to promote research in this field.
- (2) Chinese scholars have created the largest number of articles in this field, publishing 122 papers, accounting for 75.31% of the total number of documents, and the number of literature citations is also the largest. This is due to the fact that the amount of renewable energy used in China has risen significantly since 2000 and is set to become the largest consumer by 2020. In addition, China was actively involved in research to explore ways to accelerate the global green economy transition through green finance and to promote global cooperation on green finance, and had introduced policy frameworks and planning for a green or renewable energy transition. Followed by Pakistan and Malaysia with 24 and 16 articles respectively. Japanese scholars have the highest average number of citations for their articles, at 57.21, indicating that their publications are more recognised in the field. Therefore, we recommend that researchers from Vietnam, Emirates, England and other countries actively engage in academic exchanges with researchers from these countries.
- (3) Co-occurrence and cluster analysis of keywords revealed that this field has created a large number of research themes, such as: “green finance”, “economic-growth”, “renewable energy”, “CO2 emissions”, “consumption”, “investment” and “innovation”. And carbon dioxide emissions intensity has been widely studied and researched by scholars.
- (4) The analysis of timezone and timeline picture reveals that the research hotspots in the field are constantly changing, and a closer analysis of citation tree rings can further understand the trend of hotspot change. The history of research development can be divided into three phases: initial period (2012 to 2017), development period (2017 to 2020) and outbreak period (2021 to 2022). During the outbreak period the number of research publications in the field increases rapidly and the number of keywords increases considerably compared to the previous period.
- (5) Relevant studies around the world have contributed to the development of the field and have covered many themes, which can be divided into four distinct themes based on the thematic map analysis. The core topics are “Environmental Protection and Sustainable Development”, “Social Phenomena”, “Environmental Governance and Practice”, “China Green Finance”, “Green Finance” and “Economic Development and Environment”.

Among them, the intrinsic relationship between rapid economic development and environmental protection, i.e. how to properly balance the relationship between the two, is the focus and core direction of research in this field, but it needs to be explored more deeply and comprehensively by us in the future.

The value of green theory is that it can help people understand and encourage the prioritisation of future ecological and social values over short-term economic benefits ([Dyer, 2018](#)). However, the vulnerability of human health and economy is real in the face of the deteriorating climate environment, and the impact of green finance on renewable energy will be greatly impacted by the increasing risk of climate change ([Alharbi, Al Mamun, Boubaker, & Rizvi, 2023](#)). Renewable energy development is crucial to the energy transformation of the structure and environmental emission reduction, and the efficient use and development of relevant innovative green financial tools can promote the future transformation deployment plan of renewable energy ([Zheng, Du, & Wang, 2023](#)). In this background, we see great potential for green finance to contribute to the energy- and environment-related sustainable development of future societies (e.g. [Zheng, Du, & Wang, 2023](#); [Rasoulnezhad & Taghizadeh-Hesary, 2022](#); [Bakry, Mallik, Nghiem, Sinha, & Vo, 2023](#)).

With the influence of a rapidly changing international political environment, the likelihood that green finance will encounter new problems in the future is higher ([Sharma, Verma, Shahbaz, Gupta, & Chopra, 2022](#)). In addition, studies have emphasized the need for an interdisciplinary perspective on the topic of green finance, including the positive balance and response to the relationship between investment and ecology or climate ([Muganyi, Yan, & Sun, 2021](#); [Sharma, Verma, Shahbaz, Gupta, & Chopra, 2022](#)). On the one hand, the deep integration of the traditional financial industry with digital technology has contributed to the rapid development of digital finance in recent years ([Jiang, Guo, & Wu, 2022](#)). Digital finance can be defined as innovative financial products, software, services and infrastructure ([Gomber, Koch, & Siering, 2017](#); [Ozili, 2018](#)), and it can contribute to the quality development of financial services consumers, digital financial providers, governments and delivery variables, and even the economy as a whole ([Jiang, Wang, Ren, & Xie, 2021](#)). [Huang, Tao, Luo, Ye, and Lei \(2022\)](#) demonstrate that digital finance plays a critical role in corporate investment activities, and they find that digital finance can influence the efficiency of corporate investment and resource allocation by encouraging corporate innovation and alleviating financing constraints. In addition, [Jiang, Guo, and Wu \(2022\)](#) conclude that digital finance has the negative effect of discouraging green investment in digital inclusive finance company, but can facilitate financial investment by companies. On the other hand, as renewable energy is a capital and technology intensive industry, it requires extensive investment activities and technological innovation ([Liu & Zeng, 2017](#)) and governments around the world have introduced relevant renewable energy policies, mostly aimed at providing financial incentives for high quality development of renewable energy and related investments ([Kozlova & Collan, 2020](#)). There is a large number of studies on renewable energy investments (e.g. exploring the attractiveness of renewable energy investments to investors ([Kozlova & Collan, 2020](#)); the role of green financial development and the efficiency of renewable energy investments ([He, Liu, Zhong, Wang, & Xia, 2019](#)); and assessing renewable energy investments based on system dynamics risk ([Liu, & Zeng, 2017](#)), but there is little valuable literature on the role of renewable energy in affecting ecosystems and climate ([He, Iqbal, & Su, 2023](#)). In addition, the literature has found that increasing investment in renewable energy can increase carbon dioxide emissions ([Yang, Zhang, Liu, & Zhou, 2022](#)). Finally, [Peng, Huang, and Zhang \(2023\)](#) found empirically that green investment significantly increased the level of green ecology in China, but the contribution was only in the eastern region, and it is worth considering that environmental regulation inhibits the positive effects of green investment on green ecology. Furthermore, the importance of

renewable energy investments in achieving sustainability goals has been demonstrated (He, Iqbal, & Su, 2023).

### Practical implications

The investigate of the link between green finance and energy, as an active and cutting-edge interdisciplinary discipline, still has great scope for development. This paper is therefore highly valuable in sorting out the research lineage from the perspectives of bibliometrics, and can provide researchers in the field with more cutting-edge research directions and clearer thoughts for the future. Specifically:

- (1) Can help scholars interested in the field of study to develop a more systematic and clear framework for research and to gain insight into the progress process of this field;
- (2) The study analyzed the evolution of high-frequency keywords, visualized the clusters and summarized the analysis, which can help researchers and scholars better comprehend the centre point and hotspots of research in this field (e.g. green finance, economic-growth, renewable energy, CO2 emissions), and also provide scholars with references for future research.
- (3) This study analyses the core journals in the field and provides scholars with assistance in finding research-related literature in the future, as well as being able to help relevant scholars select appropriate journals when submitting papers on the topic in the future.

### Policy recommendations

Firstly, it is recommended that national governments and relevant authorities should carry out integrated planning of relevant development strategies and specific completion plans in accordance with the current situation and resource characteristics of green finance development in their regions. And there is also a need to strengthen cooperation to enable better exchange, integration and innovation of advanced technologies from different countries, so as to form a coordinated development mechanism among governments, banks and enterprises of different countries, and ultimately achieve the goal of promoting the transformation of global green and low-carbon industries and the restructuring and optimisation of energy.

Secondly, relevant research institutions or departments need to strengthen their research on the effects of green finance on the optimisation of energy structures, and also improve the global market-based system for the development of green finance, so as to make the financing channels of enterprises in individual countries more diversified. At the same time, the government should provide more financial support and policy incentives so that green financial institutions can create more diversified green financial products and turn them into an important driver for clean energy progress.

Thirdly, in order to work together to build a more environmentally friendly and green society and to achieve the goal of global sustainable development, countries should have a strong sense of environmental protection and social responsibility. The sustainable growth of society requires our joint efforts, as well as more diverse technologies and a richer range of ideas to construct. If we can promote economic progress and also contribute to the growth of energy and ecological environment, the prospect of building a prosperous society of human beings and nature will be closer to us.

### Limitations and future research

There are limitations to this study due to some factors. Firstly, because bibliometric analysis requires excellent data, and also to ensure that more complete data can be collected, this study only used the journal papers in the SCI-EXPANDED and SSCI index in Web of Science Core Collection, which will create the challenge that the data analysis is

not comprehensive enough. Second, due to the need to analyze and interpret the data, the author's subjectivity will inevitably arise in this process.

With the development of financial technology and people's concerns about environmental energy issues, research into green finance and energy around the world will continue to develop dynamically and will continue to be of great value to the sustainability of the planet in the future. Secondly, it is necessary to positively discuss with scholars in the field of green finance and energy, so as to understand the frontier dynamics of the field and improve the objective cognition of this field.

### CRedit authorship contribution statement

**Zhibin Tao:** Conceptualization, Methodology, Writing – original draft. **Jiaxiao Chao:** Conceptualization, Methodology, Writing – original draft.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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