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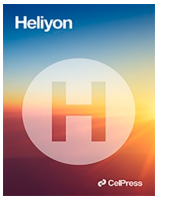

Research article

Research landscape of energy transition and green finance: A bibliometric analysis

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A R T I C L E I N F O

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A B S T R A C T

This study utilizes bibliometric analysis to examine historical and present research patterns in the area of energy transition and green finance and to forecast potential future domains. Using the bibliometric method, 328 scholarly articles from the Web of Science database were evaluated. This paper identifies influential publications, maps the research landscape, and forecasts emerging tendencies through co-citation and co-word analyses. Co-citation analysis found three main clusters, while co-word analysis revealed four main clusters. Despite the growing significance of research on energy transition and green finance research, further in-depth investigation is necessary to offer a thorough depiction of the research domain. This research represents a pioneering endeavour in the utilization of bibliometric analysis to investigate the interrelationship between two items. It offers valuable insights into the rapidly expanding field of energy transition and green finance, effectively highlighting its contours and indicating potential future developments.

1. Introduction

Rapid industrialization has resulted in significant environmental issues, such as increased pollution and resource scarcity [1,2]. Environmental issues are now posing serious threats to human well-being [3,4]. As we address pressures such as resource scarcity, social advancement, and environmental protection, rational energy utilization becomes critical for global sustainability, emphasising the need for energy transition as traditional reserves deplete [5,6]. Under such circumstances, energy transition implies the transition from fossil fuel-dependent energy sources to those that produce zero carbon emissions [7]. The emergence of clean and low-carbon energy has captured growing attention [8,9]. Currently, the global landscape is amidst a period of energy revolution and

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transition, where the international focus on energy is progressively shifting from traditional fossil fuels like petroleum and gas to encompass renewable energy and energy efficiency [10]. For instance, the United States plans a 50 % greenhouse gas reduction by 2030; Japan targets a 46–50 % emission cut by 2030 from 2013 levels; Canada strengthens contributions for a 40–45 % reduction from 2005 by 2030; the European Union aims for a 55 % emission cut by 2030 and net zero by 2050; China announces to control coal-fired power generation projects; South Africa shifts emissions peak to 2025 [11].

In contrast to the mature market of traditional energy, renewable energy is constrained by technological limitations and financial barriers [12]. Traditional finance prioritizes profit maximization, focusing on risk-return optimization and disregarding externalities. Due to substantial initial investments and extended payback periods, businesses and financial entities often exhibit scepticism towards pro-social or pro-environmental ventures [1]. As societal awareness of corporate externalities grows, value maximization gradually integrates considerations for diverse stakeholders, including society and the environment. Opportunities in clean technology and other environmentally favourable domains attract heightened investor interest [13,14]. In response, green finance is an innovative financial instrument bridging finance and the environmental sector [15,16]. Employing financial services, green finance decreases the support for heavy pollution and energy-intensive companies, promotes eco-conscious enterprises, lessens energy consumption intensity, and consequently fosters harmonized advancement encompassing economic growth and environmental protection [6].

Practically, the significance of green finance's potential contribution to developing renewable energy is increasingly highlighted [15]. Under this circumstance, recent examinations into green finance and carbon emission reduction have transpired. The literature has concentrated on financial instruments linked to climate, including carbon finance [17], carbon tax [18], and green supply chains [19]. Furthermore, multiple bibliometric analyses related to carbon emission reduction have been executed. For example, Zhang and Liang [20] scrutinize collaborative efforts on carbon emission reduction, and Huang et al. [21] pinpoint empirical methodologies for modelling sectoral carbon emissions in China. However, although some studies touch upon green finance [22,23], and explore the effect of green finance on mitigating carbon emissions [24], they neglect an in-depth exploration of the specific amalgamation of green finance and energy transition. The existing bibliometric literature primarily focuses on separate studies of green finance or energy transition, with limited attention to the integrated development of both, which serves as the motivation for this paper. At the stage of transitioning towards renewable energy sources, it is important to consolidate existing knowledge to find the most salient issues.

This bibliometric study is a pioneering effort to investigate the growing fields of energy transition and green finance, and it is the first of its kind to connect these two domains. The goal of this bibliometric study is to delve into the increasingly important fields of energy transition and green finance, as well as the academic terrain that underpins these areas. This investigation requires a methodical approach that allows for an assessment of the extent and nature of academic contributions while highlighting emerging trends in scholarly discourse. The study intends to map the evolution of these domains by thoroughly examining publication trends and thus sketching a development trajectory in the fields of energy transition and green finance.

This research is driven by a central question: What key thematic constructs, dominant subjects, and emerging areas exist in energy transition and green finance research, and how do these elements shape future trajectories? The study employs bibliometric analysis to provide a lens through which the progression, current dynamics, and potential future directions of energy transition and green finance research can be viewed. This method is invaluable for identifying critical research pathways, gaps, and influences, ultimately serving as a compass for academics and practitioners in the industry. It enables them to stay up to date on developments, make sound strategic decisions, and broaden their collective understanding of these critical areas.

The study emphasises the importance of staying current on literature trends in order to develop effective green finance policies and track progress in the energy transition. To that end, the study conducts a bibliometric analysis of relevant literature published between 2012 and 2023. This approach not only fills existing knowledge gaps but also sheds light on the field's evolution, providing critical insights into the current state and future direction of the interaction between energy transition and green finance to researchers, policymakers, and industry experts.

This study differs from previous research in that it employs bibliometric analysis to investigate the interrelationship between energy transition and green finance. The research aims to gain a thorough understanding of these topics and is guided by two specific research objectives.

(1) To identify influential past research works and current prevalent themes in energy transition and green finance using co-citation analysis.
(2) To uncover thematic structures, dominant topics, and emerging areas in energy transition and green finance research, with the goal of predicting future trends and potential focus areas using co-word analysis.

2. Literature review

Green finance constitutes a pivotal financial mechanism closely tied to environmental conservation [25]. Energy transition initiatives can be propelled through the advancement of green finance [15]. Theoretical studies have explored the correlation between green finance and energy transition through case studies from various countries. In the context of China, Lee [26] examines the green finance-sustainability linkage and reveals a favourable effect on green energy projects. Drawing from the case of Costa Rica, Goldstein [27] emphasises the necessity of global green economic reforms, functioning as a potent catalyst to boost green energy investment and reduce environmental pollution. Prakash and Sethi [28] suggest green bonds as the means to bridge the financing gap for India to meet sustainable development goals. Ainou et al. [29] recommend enhancing Morocco's energy transition through increased use of renewables and efficient technologies, which can be achieved by implementing green investment projects. Khalil et al. [30] find that green finance, green innovation, and fintech help in achieving sustainable development goals in Gulf countries.

The relationship between energy transition and green finance can be influenced by other factors, for example, financial market mechanisms and government policies [31]. Meo and Karim [32] use quantile regression to verify that market conditions and mechanisms are instrumental in establishing a favourable association between green financing and carbon dioxide (CO2) emissions reduction. By the daily data from December 2008 to December 2019, Nguyen et al. [33] demonstrate the influence of investment time and frequency horizons on green finance's impact on the promotion of clean energy. Demirtaş et al. [34] illustrate that institutional quality positively affects green investments, and military spending reduces green investments. Hou et al. [35] find that green finance contributes significantly to the advancement of renewable energy in developed nations, nations with elevated levels of green financial development, and those with stringent environmental regulations. However, they argue that green finance does not exhibit a substantial impact in less developed countries, nations with lower levels of green financial development, and those with lax environmental regulations. Considering the multifaceted determinants shaping the association between green finance and energy transition, a rationale exists for delving deeper into their intricate interrelationship, which serves as the motivation for this paper.

Although previous studies have explored how green finance stimulates energy transition, they are topic-limited. Besides, the literature on energy transition and green finance is more theoretical and qualitative in interpretation, while quantitative research techniques have made fewer contributions in the past. The bibliometric analysis proposes a systematic research framework that delineates pivotal scholarly publications, maps a cognitive structure of knowledge, and prognosticating nascent trends by co-citation and co-word analyses. For instance, Zhong and Lin [36] perform a study of bibliometrics and content analysis to summarize studies related to the development of the economic field during the COVID-19 epidemic. Zhang et al. [37] also utilize bibliometric analysis to understand the evolution of Artificial Intelligence in Renewable Energy (AI&RE) research from 2006 to 2022. Additionally, Zhang et al. [38] use 7154 publications from the Web of Science Core Collection and find that risk management has been involved in various fields such as credit, supply chain, health emergency, and disaster. By the bibliometric analysis, Chen et al. [39] reveal that purification or removal techniques can effectively remove pharmaceutical compounds from the water environment. They also find that the efficient detection of emerging contaminants and the optimization of removal methods are current challenges in their field.

In the field of green finance, Zhang et al. [40] utilize bibliometric analysis to summarize the current status and emerging trends in green finance. Through keyword analysis, they find that green finance needs to be considered an interdisciplinary research topic that encompasses and deals with policies, investment and governance on financing and investment in climate adaptation. Their citation analysis underscores the need to incorporate mainstream finance techniques and models in the study of green finance issues. In a separate study, Naeem et al. [41] examined 1413 documents in the SCOPUS database (1990–2021), revealing three key areas in green and sustainable finance: green and sustainable finance, including socially responsible investments, green finance, and climate finance.

In the field of energy transition, Zhang et al. [42] conducted a systematic review of 2191 clean energy articles, uncovering five main research streams and six emerging areas. Francisco [43] also identifies key trends and academic contributions in renewable energies and sustainable development by bibliometric analysis. Zhang et al. [9] utilize the Web of Science Core Collection for a bibliometric analysis covering 2006 to 2021. They emphasise achieving carbon neutrality by advocating for reduced carbon emissions through the widespread adoption of renewable energy. Additionally, they stress the importance of leveraging carbon sinks and employing carbon capture, utilization, and storage methods.

Concerning the utilization of bibliometric analysis in the examination of the connection between green finance and other factors, Zhang et al. [24] apply a bibliometric analysis to review research on green finance and carbon emission reduction based on the literature from 2010 to 2021 in the Web of Science core database. Keyword analyses highlight deforestation, carbon markets, and financial development as significant research topics. Besides, the research hotspots include clean development mechanisms, adaptation, carbon market, and sequestration. Kwong et al. [44] conduct a bibliometric analysis of green finance and FinTech research up to 2022, suggesting future directions such as the investment facet of green finance, the application facet of FinTech, the regulatory environment in some developing countries, and an emphasis on Green FinTech research based on the Web of Science database. Therefore, the current paper proposes two hypotheses as follows:

Hypothesis 1. Co-citation analysis may identify specific papers related to green finance and emissions that significantly influence the shaping of key topics within the field of green finance and energy transition.

Hypothesis 2. Co-word analysis may identify keywords such as sustainable development, economic growth, green finance, and emissions that are increasingly important in the field of green finance and energy transition, signalling the emergence of new research topics or subfields.

Verifying these two hypotheses assists researchers in exploring theories and addressing research gaps to address the interrelationship between energy transition and green finance. Practitioners can also utilize the findings to formulate practical plans, comprehend stakeholder dynamics, address diverse developmental needs, and tackle potential future issues.

3. Methods

3.1. Bibliometric approach

Bibliometric analysis, through examination of existing publications encompassing authors, keywords, publishing locations, sources and countries, enables the comprehensive evaluation of the status within a specific research area [45,46]. This analytical approach facilitates an assessment of the developmental trajectory and potential of a designated topic [47]. Currently, within diverse research fields, the employment of bibliometric analysis has been instrumental in uncovering the evolution of literature focused on a target theme, alongside an exploration of publishing sources and collaborative relationships among authors and countries/regions [48,49].

The primary strength of bibliometric analysis lies in the transformation of intangible scientific literature into a structured and manageable entity [50,51]. Co-citation and co-word analysis deepen structural evaluation and future direction mapping [52].

Co-citation analysis hinges upon tallying concurrent citations and utilizes co-citation counts to assess similarities among documents, journals, and authors [46]. The examination of research themes involves the organization of scholarly literature, thereby unveiling coherence and evolutionary trends [53,54]. Prominent publications derive their significance from quantified co-cited counts and link strength [55]. The frequency of keywords in articles is calculated by co-word analysis [56]. It explores the interactions among keywords, thereby indicating influential topics [57]. By extracting from titles, keywords, or abstracts, co-word analysis assesses trend evolution and concept connections [40,58].

3.2. Research design and data collection procedure

The study begins by carefully selecting literature that matches the search criteria. Following that, a thorough examination of both quantitative and qualitative aspects of the literature is carried out. The goal of this analysis is to produce meaningful results and draw appropriate conclusions.

The first step is to gather information from the Web of Science (WOS) database. Table 1 describes the procedure and parameters used for the literature search and screening. WOS databases are chosen for bibliometric analysis because of their high quality and breadth of content [59]. These databases are the most popular and trustworthy repositories of scholarly publication and citation data, providing extensive access to highly regarded research from around the world [60,61]. Recent literature indicates that it is common to utilize a single database, such as the Web of Science (WoS), which is widely recognised as a highly reliable source, when conducting bibliometric analyses. This method was developed in response to the requirement of manually merging data across multiple formats, which carries the risk of human error [62]. Alternative databases, such as Scopus and Google Scholar, may provide different results, such as a broader range of indexed publications [63]. Despite this limitation, relying solely on the WoS database is often seen as limiting the number of publications indexed in prestigious journals, potentially compromising quality [48].

As mentioned in the “WOS Database” section, it refers to a comprehensive examination of all WOS databases. The “Time Period” covers all works from database inception until August 11, 2023. In the “Search Field” section, the ‘TOPIC’ search field, which encompasses title, abstract, and keywords, is utilized. This choice ensures a broad yet relevant collection of literature, offering a comprehensive approach to capturing all pertinent studies in the research area. The “Search Keywords” column reveals those articles containing the keywords (“energy transition*" or “green energy*" or “renewable energy*" or “alternative energy*" or “low-carbon energy*" or “environmentally friendly energy*" AND “green finance*" or “sustainable finance*" or “environmental finance*") were the main focus. The specified keywords are carefully selected to encompass a wide spectrum of research areas within the broader topics of energy transition and green finance. The use of asterisks (*) allows for the inclusion of various terminologies and phrases that fall under these key themes. The “Citation Topics Meso” column indicates that the study included all meso-level topics associated with the keywords. By including all meso citation topics, the search is intentionally broad to encompass interdisciplinary research that intersects with energy transition and green finance, recognizing the multifaceted nature of these subjects. “Document Type” considered all document types, whereas “Languages” suggests that all languages were considered. This comprehensive procedure produced 328 articles for further examination. Including all document types ensures a comprehensive collection of research outputs, which may include articles, reviews, conference papers, and other documents. This approach acknowledges the importance of various forms of scholarly communication in comprehending the full scope of the research landscape. Furthermore, taking into account publications in all languages allows for a global perspective on the subject, recognizing that significant contributions to these fields come from a variety of regions and linguistic backgrounds.

In the second phase, a quantitative bibliometric analysis was conducted to clarify research on energy transition and green finance. This phase encompasses two stages: (1) an analysis of annual publication trends, and (2) a scientific mapping process. Within the scientific mapping step, version 1.6.18 of the bibliometric software VOSviewer was utilized. Network analysis was executed based on co-citation and keyword co-occurrence here, aiming to investigate the network of research collaborations and illuminate the latest academic trends. VOSviewer, an open-source tool, offers sufficient functions for visualizing bibliometric networks and scientifically depicting literature [50]. It involves clustering scattered knowledge across diverse fields based on similarities and relevancies. Within the visual network, nodes represent specific entities, such as references and keywords. Nodes with high similarity are clustered together and differentiated from other clusters by color, while nodes with lower similarity are separated whenever possible [64].

Finally, in the third stage, this study encompassed a qualitative thematic analysis of the literature, presented through tables and

Table 1
Search string.

WOS Database	ALL
Time Period	Up to August 11, 2023
Search field	TOPIC
Search keywords	“Energy transition*" or “green energy*" or “renewable energy*" or “alternative energy*" or “low-carbon energy*" or “environmentally friendly energy*" AND “green finance*" or “sustainable finance*" or “environmental finance*"
Citation Topics Meso	ALL
Document Type	ALL
Languages	ALL

narrative summaries. Thematic analysis necessitated authors' comprehensive reading of texts to become familiar with their substantive content and to assign a representative name to each identified cluster [65].

4. Result and discussion

This section encompasses statistical analysis of publication trends, co-citation analysis, and co-word analysis.

4.1. Publication trends and descriptive analysis

Web of Science search retrieved 6871 citations for selected articles (N = 328), with 5647 without self-citations. The H-index stood at 44, with an average of 20.95 citations per article. The compilation of 328 articles shows a rise in demand for studies related to energy transition and green finance. Although this research started in 2012, it was not until 2019 that significant advancements were made. Since that time, the volume of pertinent publications has grown dramatically. Fig. 1 depicts article publications and citations from 2012 to August 11, 2023.

4.2. Co-citation analysis

This study employs document co-citation analysis over author co-citation analysis. The choice of document analysis aligns with the study's aim to map the intellectual framework of a specific field because author co-citation analysis risks misinterpreting findings due to authors' involvement in multiple research fields, as suggested by Hota et al. [66]. Co-citation analysis used 62 as the threshold, yielding a total of 62 cited references. Fig. 2 displays network analysis, while Table 2 showcases the top ten co-cited references. Zhang et al. [67] were cited 56 times, Meo and Karim [32] were cited 39 times, and Taghizadeh-Hesary and Yoshino [68] were cited 57 times.

Co-citation analysis reveals three distinct clusters, each with a unique thematic emphasis. These clusters represent publications with thematic affinities and connections. Nodes of the same color note clusters with shared topics. Each cluster is identified and defined as follows:

- Cluster 1 (Red) includes 28 publications with the title **"Green finance, emissions and sustainable development".** The publications in Cluster 1 emphasise green finance as a crucial tool for combating climate change, especially when it comes to energy-related and emissions-related concerns. This is consistent with the broader objectives of the Sustainable Development Goals (SDGs). The discovery that green finance is important in enabling credit provisioning in the energy conservation and environmental protection sector is significant because it emphasises the importance of financial instruments in accelerating energy transitions [69]. According to Jin et al. [70], green finance is more of a catalyst for changing energy practices than a support system. He et al. [71] describe how green finance can assist renewable energy companies in investing more efficiently, particularly those struggling with excessive investment. This study is significant because it demonstrates the delicate balance that green finance maintains when financing and optimising investments in renewable energy, a critical component of the energy transition. Ren et al. [72] discovered a long-term equilibrium relationship between carbon intensity, green finance, and alternative energy consumption. This implies that green finance has a significant impact on the consumption of alternative energy sources and that the effects are gradual rather than instantaneous. Policymakers and investors who want to organise and commit to green finance initiatives must understand the temporal dimension of the issue. According to Zhou et al. [73], green finance emphasises the environmental impact of financial

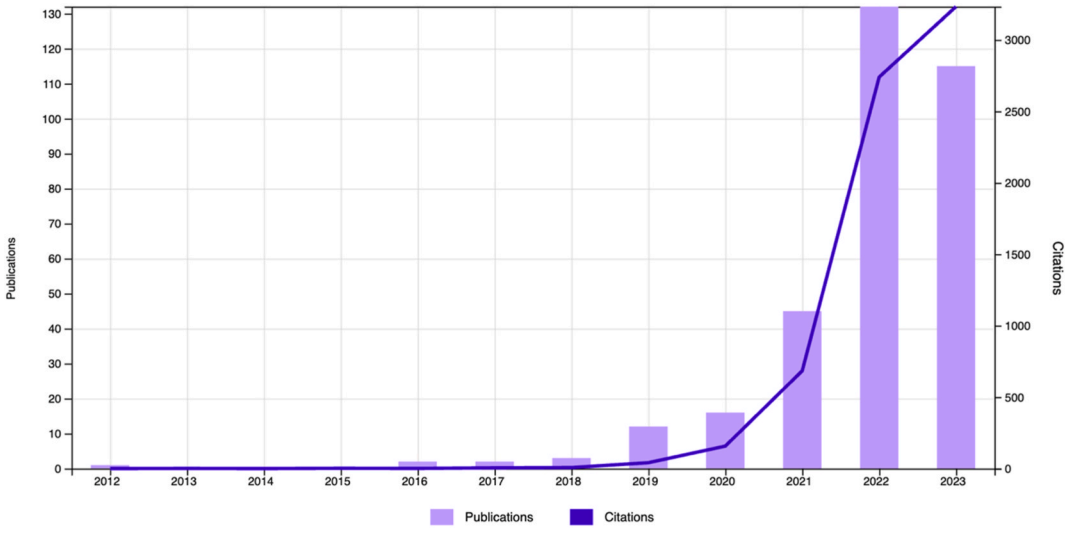

Fig. 1. Number of publications and citations, 2012 to August 11, 2023. (Source: Web of Science).

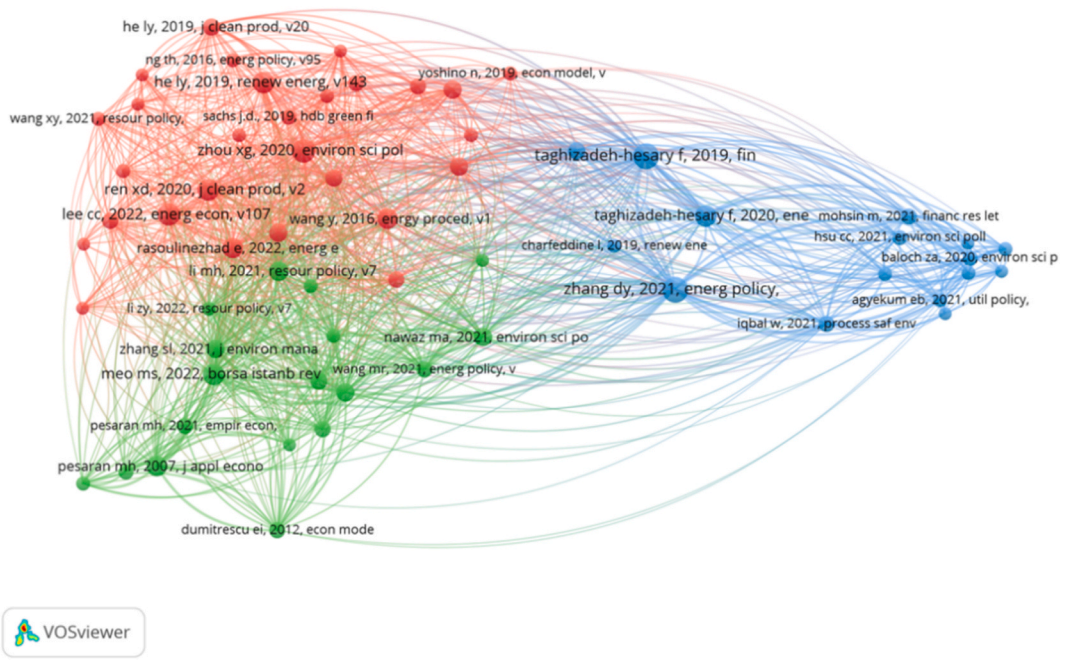

Fig. 2. Co-citation analysis (VOSviewer visualization).

Table 2
Top 10 documents ranked by co-citation and total link strength.

No.	Documents	Citation	Total link strength
1	Zhang, D., Mohsin, M., Rasheed, A. K., Chang, Y., & Taghizadeh-Hesary, F. (2021). Public spending and green economic growth in BRI region: mediating role of green finance. *Energy Policy*, *153*, 112256.	56	458
2	Meo, M. S., & Abd Karim, M. Z. (2022). The role of green finance in reducing CO2 emissions: An empirical analysis. *Borsa Istanbul Review*, *22*(1), 169–178.	39	394
3	Taghizadeh-Hesary, F., & Yoshino, N. (2019). The way to induce private participation in green finance and investment. *Finance Research Letters*, *31*, 98–103.	57	383
4	Lee, C. C., & Lee, C. C. (2022). How does green finance affect green total factor productivity? Evidence from China. *Energy Economics*, *107*, 105863.	43	372
5	Zhou, X., Tang, X., & Zhang, R. (2020). Impact of green finance on economic development and environmental quality: a study based on provincial panel data from China. *Environmental Science and Pollution Research*, *27*, 19915–19932.	45	347
6	Li, M., Hamawandy, N. M., Wahid, F., Rjoub, H., & Bao, Z. (2021). Renewable energy resources investment and green finance: Evidence from China. *Resources Policy*, *74*, 102402.	32	307
7	He, L., Liu, R., Zhong, Z., Wang, D., & Xia, Y. (2019). Can green financial development promote renewable energy investment efficiency? A consideration of bank credit. *Renewable Energy*, *143*, 974–984.	39	300
8	Ren, X., Shao, Q., & Zhong, R. (2020). Nexus between green finance, non-fossil energy use, and carbon intensity: Empirical evidence from China based on a vector error correction model. *Journal of Cleaner Production*, *277*, 122844.	39	296
9	Muganyi, T., Yan, L., & Sun, H. P. (2021). Green finance, fintech and environmental protection: Evidence from China. *Environmental Science and Ecotechnology*, *7*, 100107.	28	281
10	Jin, Y., Gao, X., & Wang, M. (2021). The financing efficiency of listed energy conservation and environmental protection firms: evidence and implications for green finance in China. *Energy Policy*, *153*, 112254.	28	264

Source: VOSviewer analysis on author interpretation.

strategies by reducing CO2 emissions and industrial pollution. By directly connecting financial mechanisms to environmental outcomes, this feature establishes a strong link between green finance and environmental sustainability. By better understanding the function and effects of green finance, policymakers can create more effective financial incentives and environmental regulations. These insights can be used by practitioners in the energy and finance sectors to inform business strategies and investment decisions that are in line with sustainable development goals.

- Cluster 2 (Green) contains 18 publications with the title "**Impacting factors on green finance-emissions connection**". In this cluster, these influencing factors are divided into three categories: social factors, scientific technology, and market conditions. Each of these categories contains numerous components that are critical to determining the dynamics of green finance and its impact on emissions. According to Meo and Karim [32], the intensity of the green finance-emissions link varies across nations due to differences in market conditions. These circumstances include not only general market patterns such as bullish or bearish tendencies,

but also elements specific to individual countries that affect green finance. To expand on this understanding, Li et al. [74] discuss how external economic events, such as the COVID-19 pandemic recession, can stymie the positive effects of green finance, specifically private investment in renewable energy. This implies that market stability and economic health are required for green finance initiatives to be successful. According to Muganyi et al. [75], the role of fintech demonstrates how big data and, in particular, artificial intelligence can significantly improve the efficacy of green finance. These technologies enable more focused and efficient environmental investment by reducing industrial emissions and increasing environmental investments. This finding implies that, in order to address environmental challenges, technology and finance are increasingly convergent. Environmental and climate change policies, interest rate dynamics, religious orientations, and concerns about social inclusivity and equity are all highlighted by Akomea-Frimpong et al. [76]. These elements are critical in determining banks' green finance policies. Furthermore, as Li et al. [77] point out, green regulations play a significant role in strengthening the link between green finance and renewable energy investments. On the other hand, it becomes clear that how oil price fluctuations and geopolitical risks affect clean energy investments is one of the most important factors to consider.

- Cluster 3 (Blue) contains 16 publications with the title "**Green finance instruments**". This cluster provides insight into how financial instruments and approaches can be used to overcome the challenges associated with developing green energy projects, such as a lack of long-term funding, low rates of return, a variety of risks, and market participants' limited capabilities. Taghizadeh-Hesary and Yoshino [68,78] discuss practical solutions to these problems. These strategies include the use of spillover taxes to increase project returns and financial institutions promoting eco-friendly investments. Furthermore, they support the establishment of community-based trust funds as well as the use of financial and policy de-risking techniques to mitigate the risks associated with green investments. These strategies emphasise the importance of developing innovative financial solutions that can increase the viability and investor appeal of green energy projects. Green bonds should be encouraged in the renewable energy sector, according to Mohsin et al. [79]. They propose developing a low-carbon finance index that considers a number of financial, environmental, and energy-related variables. Green bonds are a wise investment because they fill a funding gap for renewable energy projects by providing a means to raise funds for environmentally friendly projects. Alemzero et al. [80] concentrate on green investment as a tool, highlighting the necessity of raising regional investments in energy infrastructure and renewable energy. This point of view emphasises how crucial it is to concentrate investments on particular industries and geographical areas in order to guarantee that the advantages of green finance are fairly distributed and support the more general objectives of energy transition and sustainable development.

Table 3 summarizes the co-citation analysis, which includes cluster labels, the number of publications, and representative publications. Accordingly, Hypothesis 1 has been confirmed.

4.3. Co-occurrence of keyword

Each identified keyword appeared at least 8 times, and 65 keywords were determined as the final selection for co-word analysis. Co-word analysis unveiled that "green finance" appeared 211 times, making it the most used keyword. "Renewable energy" and " CO2 emissions" were second and third, with 137 and 68 occurrences, respectively. The top 15 co-occurring keywords are shown in Table 4. Fig. 3 shows the result of the co-word analysis, which is composed of four separate but seemingly connected clusters. The following traits of each cluster are assessed and discussed:bib32

- Cluster 1 (Red) contains 22 keywords and is titled "**Chinese economic growth and environmental sustainability**". The complex interplay between economic growth and environmental sustainability, particularly in China, represents a pivotal trend that is shaping the global landscape. This trend encapsulates a critical intersection in global environmental discourse: balancing rapid economic advancement with environmental imperatives, a challenge faced globally but exemplified particularly in the context of China. Empirical evidence, such as the findings of Abid et al. [81], has shed light on the complex relationship between growth, as driven by urbanization, trade, and financial development, and its effects on CO2 emissions and energy consumption. This relationship emphasises the numerous difficulties that emerging economies face. The rise of China's economy has led to increased consumption, particularly of nonrenewable energy sources, resulting in higher emissions [82]. Such energy consumption patterns and their environmental consequences are critical for understanding the dynamics at work in the energy transition and green finance fields. The push for technology-driven solutions is an important aspect of this interplay, as evidenced by China's rapid transition to renewable energy development. This transition, which is being driven by environmental concerns as well as trade and economic imperatives, is part of a larger global story. In this context, technological innovation is critical for both economic competitiveness and environmental stewardship. As a result, this transition entails more than just changing energy sources; it

Table 3
Co-citation clusters of energy transition and green finance.

Cluster	Label	Number of publications	Representative publications
1 (Red)	Green finance, emissions and sustainable development	28	[69] [70–73],
2 (Green)	Impacting factors on green finance-emissions connection	18	[32,74–77]
3 (Blue)	Green finance instruments	16	[68,78–80]

Source: VOSviewer analysis on author interpretation

Table 4
Keyword co-occurrence analysis top 15 keywords.

Rank	Keyword	Occurrences	Total link strength
1	Green finance	211	866
2	Renewable energy	137	602
3	CO2 emissions	68	404
4	Economic-growth	64	382
5	Consumption	59	366
6	China	71	332
7	Impact	46	256
8	Growth	50	247
9	Innovation	38	208
10	Sustainable development	37	194
11	Efficiency	30	159
12	Investment	29	151
13	Cointegration	24	131
14	Carbon emissions	19	117

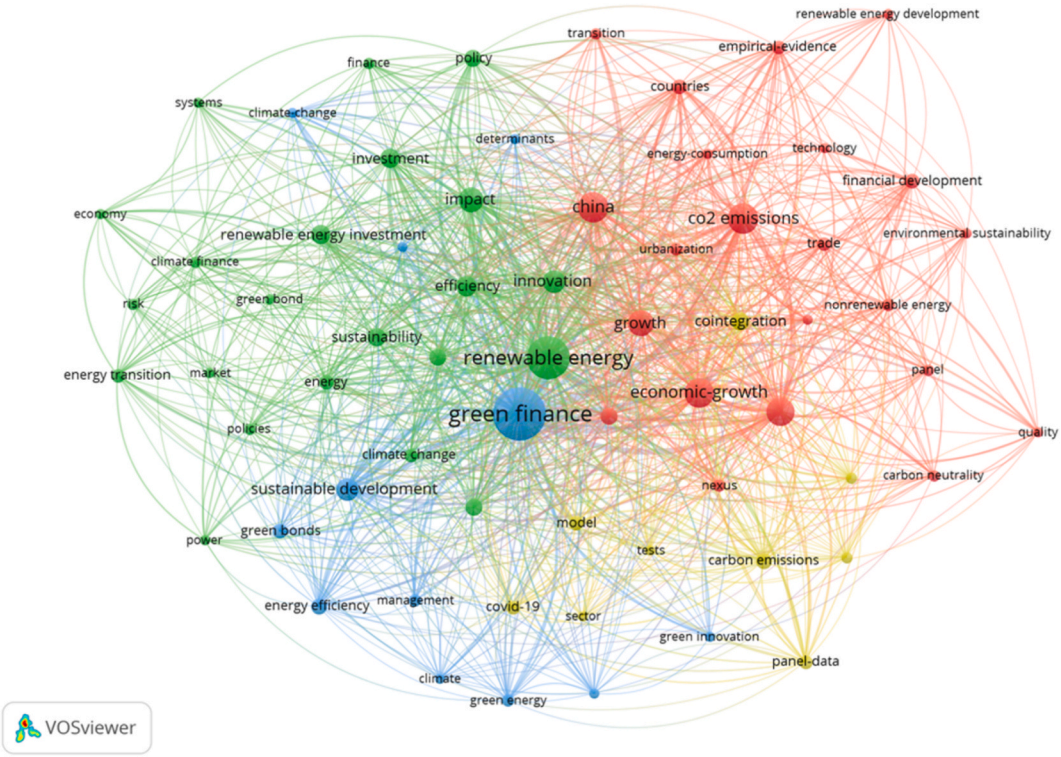

Fig. 3. Co-word analysis on energy transition and green finance (VOSviewer visualization)

entails a complete transformation of economic structures and policies. China's journey, like that of other countries, entails the difficult task of effectively balancing significant economic growth with the imperative of maintaining environmental sustainability [83]. The country's efforts to achieve carbon neutrality, as evidenced by its commitments to reduce emissions, are in line with broader global trends [84]. These efforts are not isolated, but rather part of a global shift towards more environmentally friendly policies and practices. In terms of green finance, understanding China's energy consumption and emission trends is invaluable. They inform sustainable finance investment strategies and policy formulations, which are critical for steering economic policies towards more environmentally friendly alternatives.

- Cluster 2 (Green), with 22 keywords, is titled "**Sustainable Finance in the Energy Transition**", reflects a significant convergence in the contemporary global landscape between climate change imperatives and economic strategies. This convergence is being driven by the urgent need to address the consequences of changing weather patterns and environmental deterioration. The cluster highlights the growing importance of the energy transition, or the transition from fossil-fuel-dependent energy sources to zero-carbon energy sources [7,85]. This transition is required not only for environmental reasons, but also for financial and economic ones, with sustainable finance emerging as a key tool in this paradigm shift [86]. Green bonds and other sustainable financial

Table 5
Co-word analysis on energy transition and green finance.

Cluster	label	Number of keywords	Representative Keywords
1 (Red)	Chinese economic growth and environmental sustainability	22	Carbon neutrality, China, CO2 emissions, consumption, countries, economic-growth, emissions, empirical-evidence, energy-consumption, environmental sustainability, financial development, growth, impacts, nexus, nonrenewable energy, panel, quality, renewable energy development, technology, trade, transition, urbanization.
2 (Green)	Sustainable finance in the energy transition	22	Climate change, climate finance, economy, efficiency, energy, energy transition, finance, green bond, impact, innovation, investment, market, performance, policies, power, renewable energy investment, risk, sustainable finance.
3 (Blue)	Green finance in sustainable governance	12	Climate-change, determinants, energy efficiency, environmental performance, governance, green bonds, green energy green finance, green innovation, management, sustainable development.
4 (Yellow)	Economic growth and carbon emissions in the COVID-19 landscape	9	Carbon emissions, cointegration, COVID-19, economic growth, model, panel-data, sector, tests.

Source: VOSviewer analysis on author interpretation.

mechanisms [87] are examples of the market's proactive response to climate change challenges. These instruments represent a critical point at which financial flows meet the goals of promoting low-carbon and climate-resilient development, particularly through investments in climate and environmental projects [88]. These financial instruments demonstrate the increasing convergence of economic strategies and environmental sustainability goals. Furthermore, the growing interest in investing in renewable energy reflects a dual recognition. It demonstrates not only a moral commitment to sustainability, but also an understanding of its economic benefits, particularly in terms of performance and risk reduction [89]. This shift in investment patterns reflects a broader market realisation: pursuing sustainability does not imply sacrificing efficiency and profitability. Rather, these objectives are increasingly seen as mutually beneficial and interdependent [15]. Climate finance is evolving from a specialised niche to a critical component of global investment strategy, and policies are evolving to support this trend [76,90]. This policy shift reinforces the pattern of incorporating sustainable practices into mainstream economic decision-making, thereby solidifying the role of sustainable finance in the broader economic context. This cluster emphasises the critical role of innovative financial products and strategies in easing this transition, as well as the importance of integrated approaches that balance economic growth and environmental sustainability.

- Cluster 3 (Blue), with 12 keywords, is titled "**Green finance in sustainable governance**", emphasising the recent, notable convergence of governance, management, and sustainable development, with an emphasis on the diverse field of green finance This convergence represents a paradigm shift in corporate governance, shifting away from a profit-driven approach and towards one that incorporates sustainability into the core strategy. Green finance, which includes a wide range of financial instruments such as green bonds, is leading the way in this transition. These instruments are more than just financial instruments; they are environmental change catalysts, with a focus on green energy initiatives and energy efficiency improvements. The growing urgency to combat climate change has prompted stakeholders from a wide range of industries to look more closely at the factors influencing environmental performance. Beyond basic operational obligations, the audit findings emphasise the importance of incorporating energy efficiency into the fabric of organisational governance [77]. This stands in stark contrast to traditional financial mechanisms, which frequently ignore the environmental consequences of funded projects. In the modern landscape, green finance is about more than just mobilising funds; it is also about ensuring that these funds achieve a dual goal: generating financial profits while also contributing to sustainable development [91]. This dual goal of balancing financial gains with long-term outcomes presents both challenges and opportunities. Green finance is critical to the energy transition because it prioritizes and supports projects that are consistent with global climate goals. However, a critical examination is required to determine whether these efforts are sufficient and what gaps still exist. Green finance's integration into traditional governance and management structures is complex and multifaceted. It entails manoeuvring through stakeholder expectations, regulatory frameworks, and market dynamics while also learning new skills. The responsibility, then, is to ensure that this integration is smooth and effective, and that it strikes a balance between the need for financial viability and the imperative of long-term development. Future research should focus on these aspects, in order to provide policymakers, financial institutions, and corporations with insights into how to strengthen green finance's role in sustainable governance.
- Cluster 4 (Yellow) contains 9 keywords and is titled "**Economic growth and carbon emissions in the COVID-19 landscape**". This cluster investigates the unique and significant changes that occurred in global economic sectors as a result of the COVID-19 pandemic. Scholars have focused on the relationship between economic growth and carbon emissions, which has gained prominence in recent years. Wang et al. [92] used panel-data models to uncover complex patterns in this relationship, taking into account both time dynamics and cross-sectional differences across countries or sectors. These models have been helpful in understanding how different economies react to external shocks like the pandemic. Furthermore, Nketiah et al. [93] used cointegration tests, a method for detecting long-term relationships between variables, to uncover a strong and persistent correlation between economic activities and their environmental consequences. Tourism and manufacturing industries, which rely on physical presence, were severely impacted by the pandemic. Pandemic-induced lockdowns, according to Barua [94], resulted in a significant decline in growth in these sectors. According to Chu et al. [95], this downturn coincided with a decrease in carbon emissions. However, this environmental silver lining was fleeting. As Bi [96] points out, the resurgence of economic activity following the lockdown resulted

in an increase in emissions, though the extent varied across sectors. The findings of this cluster highlight a critical dilemma: the difficulty of decoupling economic growth from environmental degradation. While the pandemic disrupted this link temporarily, the rebound of emissions with economic recovery suggests that current growth models are inherently linked to environmental impacts. This calls into question the long-term viability of post-pandemic recovery strategies, as well as the implications for environmental policy and economic restructuring. The findings of the cluster highlight the need for a more sustainable approach to economic growth, one capable of achieving both economic resilience and environmental sustainability.

Table 5 summarizes co-word analysis for energy transition and green finance literature, including cluster labels, the number of keywords, and representative keywords. Accordingly, Hypothesis 2 has been confirmed.

5. Implications

This paper examines the current status of the energy transition-green finance association. It yields illumination into the intricacies inherent in the body of literature through the application of bibliometric analysis. It provides comprehensive conceptual mapping, enhancing understanding of connections between prominent topics [53].

5.1. Theoretical implications

The findings offer profound theoretical insights for researchers in the field of energy transition and green finance regarding the research dynamics and academic collaboration by quantitative examination of literature data. The identified influential papers and emerging keywords provide a roadmap for researchers to delve deeper into specific areas that are shaping the discourse in energy transition and green finance. This can facilitate collaborative research efforts and the development of more targeted studies. Firstly, the paper provides a new perspective on the application of bibliometric analysis for future researchers. Diverging from previous literature, which focuses on singular thematic exploration, such as exclusively addressing green finance [40,41] or energy transition [9,42,43], this research represents a pioneering endeavour in the utilization of bibliometric analysis to investigate the interrelationship between two items.

Secondly, the co-citation analysis unveils the developmental trajectory and evolution of knowledge, which is beneficial for researchers to understand the front topics in the field. The application of green finance to energy transition is proposed under sustainable development, closely tied to the imperative of reducing carbon emissions and addressing climate issues [72,73]. This finding is the same as that of Muchiri et al. [97], who use co-citation analysis to verify the importance of green finance in climate change and energy policy. Apart from this, our study also reveals that market conditions, technology, and government policies have an impact on the intensity of this relationship [32,75,76]. Furthermore, financial instruments on energy transition are found to be another existing trend. Various instruments have been created, such as green bonds and green credits, to leverage the potential of green finance on energy transition [78,79]. While previous literature has addressed the importance of green financial instruments, to the best of our knowledge, this has not been posited as a distinct research domain in prior bibliometric analyses.

Thirdly, the analysis of keyword co-occurrence underscores the emergence of future subfields for researchers in the domain of energy transition and green finance. For example, the co-occurrence analysis by Muchiri et al. [97] identifies an association between green finance and sustainable development, while our paper further emphasises that China faces the challenge of balancing its significant economic growth with the crucial need to uphold environmental sustainability and aligning with the broader global trend [83,84]. This insight can guide researchers in delving into remediation studies aimed at minimizing environmental impacts, thereby securing the sustainable development of the economy. In addition, building upon Alsmadi's [98] study, which demonstrates that the most keywords used together are related to green finance and climate change, and green bonds and sustainable finance, our research posits a convergence of governance, management, and sustainable development in the field of green finance and sustainable governance. Moreover, this paper verifies COVID-19's impact on carbon emissions and economic expansion, following the research of Mashari et al. [65], which uses co-word analysis to suggest that the role of green finance in the economic recovery post-pandemic is an emerging research topic in recent years. Many manufacturing activities were halted during the pandemic, leading to a significant reduction in both economic growth and carbon emissions [94,95]. Following the end of the pandemic, although the economy began to recover, there was also a rebound in carbon emissions [96]. Therefore, further research is needed to explore how green finance can facilitate energy transition while maintaining economic growth. In summary, the findings suggest several directions for future researchers in the field of energy transition and green finance. Researchers can explore the application of bibliometric analysis as a valuable tool for investigating the interrelationship between energy transition and green finance, providing a new perspective beyond singular thematic exploration. Besides, researchers can focus on addressing challenges faced by rapidly growing economies, such as China, in balancing economic growth with environmental sustainability. Additionally, the convergence of governance, management, and sustainable development in the field of green finance and sustainable governance presents an intriguing avenue for further exploration. Future studies can also focus on understanding how green finance can effectively facilitate energy transition while supporting economic growth, particularly in the post-pandemic recovery phase.

5.2. Practical implications

Pragmatically, the study exerts substantial influence across various policymakers, industry professionals and societal aspects. Firstly, the research findings can serve as crucial references for the government in formulating financial and energy policies. In the face

of climate change, government policies are of paramount importance for both economic and environmental sustainability by guiding and regulating different parties [85,99]. Policymakers, especially in countries facing challenges in balancing economic growth with environmental sustainability, can draw insights from co-citation and co-word analysis results to develop context-specific policies. They may focus on integrating sustainable development, economic growth, and green finance into comprehensive energy transition strategies. This contributes to the development of policy strategies that support sustainable energy growth and moving towards a low-carbon economy. In specific terms, policymakers can consider the following strategies and policies to advance green finance and energy transition. Firstly, the government can integrate sustainable development goals into the national policy framework to ensure alignment between energy transition and green finance policies and specific targets. For example, the government can develop policies to help reduce sulphur dioxide and wastewater emissions [100] and improve energy efficiency [50]. Furthermore, the government can establish green regulatory frameworks to strengthen the relationship between green financing and renewable energy investment [77], protect investors' interests, and maintain market stability. Policymakers can enact stringent regulations to help financial institutions align their investments with environmental principles, as well as establish transparency and accountability mechanisms to encourage financial institutions to actively engage in sustainable investments. Furthermore, the government can enact policies that encourage financial institutions to increase their investments in renewable energy projects [12,90]. This may include measures such as tax breaks, loan guarantees, or other financial incentives to help mitigate investment risks.

Furthermore, the paper discusses the expansion of financial institutions in green finance. Financial institutions can play a critical role in financing and deploying clean energy technologies, establishing themselves as key players in the transition to a sustainable energy landscape. Based on the findings, financial institutions can revise their business strategies and introduce green finance products related to energy transition, such as green bonds and green credits, to entice clients interested in investing in sustainable energy [77, 101]. To achieve the dual goals of sustainable finance and energy transition, financial institutions must have specialised knowledge and collaborate with other stakeholders. Furthermore, the call for strengthened regulatory frameworks in green finance provides clear guidelines to financial institutions [102], promoting transparent and accountable practices. This increases their credibility and encourages active participation in long-term investments.

The study also has implications for corporate strategies and investment decisions. Companies can gain a better understanding of green finance's positive impact on energy transition and identify potential challenges that may arise during the transition process. The study acts as a strategic guide for industry professionals, allowing them to better understand and address the challenges and opportunities associated with energy transition and green finance. For starters, it assists businesses in developing development paths that are not only strategic but also long-term. Professionals in the industry can optimise their operations to align with anticipated trends in sustainable development [15]. Second, financial professionals must understand the strengthened regulations and market mechanisms in green finance. Incorporating green finance and energy transition into long-term planning enables businesses to select suitable green finance instruments, such as green bonds, that align with their specific needs into portfolios [103], thereby supporting financing for energy transition projects and gaining a competitive advantage in the market. Companies must foster adaptability in order to refine strategies in response to dynamic changes in both the market and the environment. Corporations can then make a significant contribution to increasing value across environmental, societal, and economic dimensions.

Finally, the findings lend support to the Sustainable Development Goals (SDGs). SDGs include achieving affordable, reliable, sustainable, and modern energy production, as well as reducing reliance on finite resources, minimizing pollution, and combating climate change and its consequences (SDGs 7 and 13). Furthermore, green finance contributes to making cities and human settlements inclusive, safe, resilient, and sustainable by driving the adoption of renewable energy and enhancing efficiency (SDG 11) [104]. Supported by this study, we can propel the economy, society, and environment sustainability, creating a better living environment for both current and future generations. In conclusion, studying green finance's energy transition impact not only aids in guiding policy formulation and business decisions but also contributes to driving tangible progress in sustainable development and environmental preservation. Such research provides essential insights and guidance to various stakeholders for achieving a cleaner and more sustainable energy future.

6. Conclusion, limitations and future avenues

This study presents a comprehensive bibliometric review of energy transition and green finance using a quantitative method to uncover recent and emerging trends. Literature related to the energy transition-green finance association emerged in 2012 and experienced a substantial increase starting in 2019. By co-citation analysis, past and current trends are classified into three clusters: "Green finance, emissions, and sustainable development," "Impacting factors on green finance-emissions connection," and "Green finance instruments." These historical themes firstly depict the background of green finance supporting energy transition, such as addressing climate change and emissions reduction. The second research area pertains to the influencing factors of the relationship between green finance and energy transition, such as market conditions, technology, and government policies. Besides, co-citation analysis demonstrates that many scholars have analysed the roles of various financial instruments.

Simultaneously, in the co-word analysis, the generated clusters are related to emerging trends in green finance and energy transition, including "Chinese economic growth and environmental sustainability", "Sustainable finance in the energy transition", "Green finance in sustainable governance" and "Economic growth and carbon emissions in the COVID-19 landscape". The results provide scholars with more clearance about the most common keyword searches for future works. Based on the findings, there is a high likelihood that the trend of the effect of green finance on the energy transition will continue. The co-occurrence of keywords suggests that future research could focus on how each countries utilize green finance to promote energy transition and how to formulate international policies. Another two future research trends include examining the role of sustainable finance in the energy transition

process and exploring the regulation and governance of green financial instruments. The co-word analysis also identifies future trends related to economic growth and environmental sustainability. Thus, future papers could be conducted on enhancing management and governance, and leveraging green finance for a mutually beneficial energy transition and economic development after the COVID-19 period.

This research still has some limitations. Initially, bias in bibliometric analysis poses concerns. These biases encompass institutional bias, self-citation, and language bias [105]. For example, unequal distribution of citations may arise due to factors like institutional size, financial support, or research influence, leading to overemphasis on certain institutions. Besides, authors may excessively cite their own previous works, and language bias involves the weighting of literature in specific languages, which results in an inflated assessment of the impact of specific studies or studies in certain languages [106]. Secondly, recent papers need time for citation accumulation. Current relevant papers may lack impact compared to older ones, which accumulate more citations due to extended depository presence. Thus, their influence may be unassessed currently. Thirdly, citation impact mainly hinges on first authors in co-citation and other cited-based bibliometric analyses, like direct citation analysis and co-authorship [107]. These initial authors might co-author other impactful papers but are underrepresented in the present analysis. Fourthly, data source limitations arise. Although Web of Science stands as a reputable and reliable source of publications, which ensures article quality, various databases, like Scopus and Dimension, might yield different results [106]. Future studies could broaden their analysis to encompass other databases. This expansion would ensure more comprehensive coverage and enable a more diverse collection of information. Another limitation involves subjective determination in the interpretation of clusters. The author's inductive approach, based on co-citation and co-word analyses, may influence outcomes. Cluster finalization hinges on the authors' judgment, potentially causing bias [49].

To address these issues, future research could utilize systematic review and meta-analysis to accommodate bibliometric limitations, explore more databases and conduct qualitative inquiries for deeper insights into the influence of green finance' on energy transition. Interdisciplinary collaboration among fields such as finance, energy, environmental science, engineering, social sciences, and law can facilitate a comprehensive understanding of this domain and more effectively leverage green finance for energy transition advancement. Embracing the challenges and prospects of energy transition empowers researchers to contribute to addressing climate issues and achieving economic and environmental sustainability advancement.

CRediT authorship contribution statement

Jiahui Xu: Writing – original draft, Visualization, Validation, Resources, Funding acquisition, Conceptualization. **Qian Liu:** Writing – review & editing, Visualization, Resources, Conceptualization. **Walton Wider:** Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Shuhan Zhang:** Writing – review & editing, Resources. **Muhammad Ashraf Fauzi:** Writing – review & editing, Validation, Methodology, Conceptualization. **Leilei Jiang:** Writing – review & editing. **Lester Naces Udang:** Writing – review & editing. **Zhida An:** Writing – review & editing.

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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