Systematic Literature Review on the Methodological Approaches of the Efficiency of Green Investment in Renewable Energy-Based Development

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Abstract

Analysing the efficiency of investments in renewable energy-based development plays a pivotal role in maximising the benefits of transitioning to a more sustainable energy future. Examining the efficiency of these investments ensures the optimal allocation of resources to preserve the environment and promote economic growth and social well-being. Reviewing the methodologies utilised in past research enables researchers and policymakers to discern the strengths and weaknesses of various approaches. Different researchers focus on distinct aspects of renewable energy-based development by applying a solid variety of different empirical methods. The purpose of the systematic literature review of the methodological approaches is to assess the efficiency of green investment in renewable energy-based development, advance knowledge, improve the quality of the research, and guide future investigations. A bibliometric review was conducted in the field of research based on Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA 2020) guidelines. Descriptive and performance analyses, along with a bibliometric review, cover the timeline from 2018 to the present. Utilising data from Web of Science (WoS) and Scopus databases, the VOSviewer software graphically presents the results. The examination of 105 WoS and 97 Scopus articles selected based on keyword combinations identifies the main research streams, focusing on green investment and investment efficiency in renewable energy-based development. The findings enable the identification of the most productive countries, journals, authors, and their collaborative efforts, all of which significantly contribute to shaping the theoretical framework of investment efficiency and green finance. The study also traces the evolution of research on the linkages between these two areas. Moreover, the results highlight the methodologies commonly employed within this field. Analysis of the WoS and Scopus databases revealed four emerging clusters, closely interconnected in research on investment efficiency in renewable energy development. The first cluster centres on green finance; the second on environmental economics and performance; the third on efficiency; and the fourth specifically on investment efficiency. As a result of the research, it was revealed that data envelopment analysis (DEA) is one of the most reliable methods used to assess the efficiency of green investment in renewable energy-based development under conditions of risk and uncertainty. The meta-analysis further uncovers new research avenues, shedding light on potential areas for future exploration regarding the relationship between investment efficiency and green investment, and methodological approaches. The findings of the systematic literature review contribute to the academic community by summarising existing research, providing a comprehensive overview, offering recommendations, and building the foundation for further scholarly work.

Key words

investment efficiency, green investment, green finance, renewable energy, data envelopment analysis.

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Introduction

In the discourse surrounding the efficiency of investments in renewable energy-based development, several conflicting viewpoints emerge. One of the primary debates focuses on how to measure the true efficiency of green investments. Additionally, there is disagreement over whether private or public investment models are more efficient in driving the transition to renewable energy. Some researchers advocate for market-driven investments (Azhgaliyeva et al., 2023), emphasising innovation and competition (Strielkowski, 2024), while others argue that government intervention and public funding (Phan, 2024; Ziabina & Navickas, 2022) are essential to mitigate risk and ensure equitable access to renewable energy.

A better understanding of effective methodologies will aid in assessing the efficiency of green investments in renewable energy-based development for future research. By reviewing the methodologies employed in existing studies, researchers and policymakers can gain insights into the strengths and weaknesses of different approaches. This understanding can contribute to the development of more robust methodologies. Therefore, the purpose of the research is to identify effective models that can be used to assess the efficiency of green investments in renewable energy-based development, and to present the different approaches used by researchers to disseminate scientific thinking in this area. In view of this, the aim is to answer the following research question:

RQ – What models are most effective in terms of assessing the efficiency of green investment in renewable energy-based development under conditions of risk and uncertainty?

The study utilises a bibliometric analysis of scientific articles retrieved from the WoS and Scopus databases, involving the examination of 105 and 97 articles selected based on keywords, respectively. Bibliometric methods have immense potential to introduce a systematic, transparent, and replicable peer-review process and thus improve the quality of literature reviews. They help to map the structure of a research field by categorising elements such as documents, authors, journals, and keywords into diverse groups (Zupic & Čater, 2015). The shift towards renewable energy represents a major transformation in the energy landscape, aligning with global endeavours to combat climate change and establish sustainable energy systems. Moreover, it emphasises the dynamic interaction among environmental, economic, and security factors in energy policy and implementation (Kut & Pietrucha-Urbanik, 2023).

The originality of this study lies in its identification of a significant rise in the importance of renewable energy-based development and green finance. While scholars have explored various dimensions of these subjects using diverse empirical approaches, this research distinguishes itself by highlighting the prominent application of DEA methods, particularly in addressing the inherent risks and uncertainties associated with green finance and renewable energy investments.

This paper consists of five interconnected chapters and a list of references. The first chapter provides a theoretical framework based on a review of the literature on renewable energy-based development. The second chapter describes the research methodology. Chapter three presents the results of the descriptive and performance analysis, followed by a discussion conducted in the fourth chapter. Conclusions are drawn in the fifth and last chapter of the paper.

1. Literature review

The significance of renewable energy in addressing climate change and guaranteeing a stable energy future has grown significantly (Akpan & Olanrewaju, 2023). The level of research is quite broad but not homogeneous. A systematic literature review and bibliometric analysis offer valuable insights into the field of assessing the efficiency of green investment in renewable energy-based development, facilitating the analysis of current trends and providing guidelines and motivations for future research endeavours (Tripathy et al., 2024; Odilova et al., 2023; Ziabina & Pimonenko, 2020; Muhuri et al., 2019; Fahimnia et al., 2015). This approach essentially outlines the general framework and overall

structure of the research field. Kwilinski (2024) delved into the relationship between green energy and green investment, highlighting the evolution of scholarly investigation into the linkages between these two domains. Muhmad et al. (2024) confirmed the positive relationship between green finance and renewable energy development, while Łukasiewicz et al. (2022) concluded that there is no one unified definition of sustainable energy development.

Green finance has emerged as a focal point of extensive research, reflecting the growing urgency to address environmental challenges (Wang et al., 2022). This field encompasses financial instruments, strategies, and initiatives aimed at promoting environmentally sustainable investments and practices. The studies (Zhang & Zhao, 2024; Li et al., 2024; Zhang et al., 2023; Sharma et al., 2022; Wang & Wang, 2022; Zhao et al., 2022; Iqbal et al., 2021; Lyeonov et al., 2019) actively investigating the dynamics of green finance, exploring its implications for sustainable development, economic resilience, and climate change mitigation by delving into topics such as green bonds (Strielkowski, 2024; Feng et al., 2024; Lin et al., 2023; Phan, 2024; Chygryn, 2018), green investment efficiency (Sun & Waqas, 2024; Chen & Feng, 2019), renewable energy financing alternatives (Azhgaliyeva et al., 2023), green innovations (Wu & Song, 2024; Kolosok et al., 2022;), fiscal policies (Zhao et al., 2023) and the role of governmental regulation to promote the green transformation (Li et al., 2024; Kut & Pietrucha-Urbanik, 2023; Wang et al., 2023; Pan & He, 2022; Ziabina & Navickas, 2022; Liu & Luo, 2019). Fang (2023) concentrates on sustainable investment portfolios, and the integration of environmental factors into financial decision-making. Muhmad et al. (2024) proposes that combining green finance with renewable energy development accelerates the transition to a low-carbon economy and mitigates the impacts of climate change. This makes green financing crucial for facilitating the shift to renewable energy sources (RES). Iqbal et al. (2021) suggest using green finance index as prerequisite to mitigate environmental pollution risk and Jiakui et al. (2023) addresses the gap in existing literature by constructing a thorough index of green finance expansion and examining its impact on green total factor productivity within the context of energy and environmental constraints.

According to Hailiang et al. (2023), Łukasiewicz et al. (2022) and others green finance and technological innovation promote environmentally conscious growth by shifting capital from carbon-intensive industries to those using advanced technologies. A key advantage of green finance is its ability to unite developed and underdeveloped countries in the fight against pollution (Ye et al., 2023). The notion of developing and developed countries appears to be pivotal in the context of renewable energy-based development. This aspect delves into the feasibility and dynamics of transitioning towards renewable energy sources, highlighting disparities and opportunities between nations at different stages of economic and technological advancement (Mohsin et al., 2021, 2023; Kyriacou et al., 2019). Scholars and policymakers are increasingly studying how developing countries can leverage renewable energy resources to leapfrog traditional development pathways and achieve sustainable growth (Lin et al., 2023; Miskiewicz, 2022; Zeng et al., 2018), while also examining how developed nations can support and collaborate with their counterparts to accelerate the global transition towards renewable energy adoption (Gavkalova et al., 2022; Iqbal et al., 2021; D. Zhang et al., 2021). Dzwigol et al. (2023) supports previous findings that green energy, along with responsible consumption and production, can positively impact green economic growth in both developed and developing countries.

It is noteworthy that numerous scientific articles employ various DEA model variations in conjunction with the Tobit model to evaluate regional energy efficiency and analyse the impact of green finance on energy performance (Wang & Wang, 2022), to calculate the regional ecological efficiency and verify the impact of green finance (Wang et al., 2022), to examine the impact, efficiency, and policy effects of green finance on industrial transformation (Gu et al., 2021). A Tobit regression model is also developed to investigate the influence of green finance and environmental regulations on green innovation efficiency (Zhao et al., 2022). Technique for Order Preference by Similarity to an

Ideal Solution method (TOPSIS) is prioritised to assess the level of renewable energy development in Belt and Road Initiative countries (An et al., 2023), to evaluate the level of renewable energy development in different countries (Leng & Zhang, 2023), to calculate the energy dependence index (Wang et al., 2022), as well as to evaluate the sustainable development of road transport in EU (Siksnelyte-Butkiene & Streimikiene, 2022). Super-efficiency relaxation DEA model (Super-SNB) gained an attention in assessing energy efficiency (Nyangchak, 2024) and green innovation efficiency estimation (Wu & Song, 2024). Among dynamic panel regression models, the generalized estimation of moments (GMM) model is extensively used in exploring the impact of environmental regulations on green economic growth (Dzwigol et al., 2023), evaluating the importance of regulatory mechanism of green finance. Akpan & Olanrewaju (2023) employed five methodological or evaluation frameworks deemed necessary to achieve 100% renewable energy systems, while acknowledging that the existing literature lacks a comprehensive compilation of methods and evaluation approaches.

Scholars propose a variety of empirical research methods to evaluate the effectiveness and efficiency of investments in renewable energy-driven development, while also acknowledging and addressing the associated risks and uncertainties. In general, scholars seek to advance understanding and provide insights to shape policy measures aimed at fostering a financial system that is both more sustainable and resilient.

2. Methodology

The bibliometric analysis in the research field was conducted in two parts. First, descriptive analysis was performed to identify patterns and relationships that help to describe, illustrate, and usefully summarise data points by using recent and historical data. Secondly, performance analysis was conducted to provide systematic views and observations aiming to provide objective statistical data and visual feedback. The scope for systematic review was identified based on PRISMA 2020 guidelines. The key words used for data collection from Wos and Scopus databases: "data envelopment analysis (DEA)", "investment efficiency", "green finance" in the "title, abstract, keywords" category. The search was performed on 14th of September 2024 resulting in 143 records in WoS and 174 in Scopus databases. The records extracted from WoS database contained 114 articles, 27 proceeding papers, 6 early access and 1 editorial material, retracted documentation, and review article, between the period of 1998-2024. Simultaneously the records extracted for Scopus database resulted in 124 articles, 43 conference papers, 4 retracted and 1 book chapters, erratum, and review, between the period of 2005-2024. To ensure the comprehensiveness of systematic literature review the research was limited to document type "Article", papers written in English language and the year range from 2018 to 2024, ensuring that the information investigated in the research remains both new and pertinent. The studies included in the research, after applying limitations, resulted in 105 articles from the WoS database and 97 articles from the Scopus database (Table 1).

Table 1. Keywords and other search criteria.

Keywords	Fields	Limited to	Period	WoS	Scopus
DEA OR "data envelopment analysis" AND "investment efficiency" OR "green finance"	Title, abstract, keywords	1. Document type: Articles 2. Language: English	2018.01.01 – 2024.09.14	105	97

Source: own elaboration.

The productivity-based analysis in the descriptive examination offers findings highlighting the most active production years, countries, journals within the research field. Performance analysis incorporated citation, co-citation and co-occurrence analyses, which are favoured by many researchers (Kwilinski, 2024; Soliman et al., 2021; Muhuri et al., 2019; Fahimnia et al., 2015; Fetscherin

& Heinrich, 2015; Zupic & Čater, 2015) due to their ability to objectively uncover relationships between articles and content, while also aiding in the identification of thematic clusters and emerging research streams. The number of citations acts as a metric for influence, considering heavily cited articles as noteworthy. This concept is grounded in the belief that authors reference documents they consider crucial for their research (Abdelmageed & Zayed, 2020; Odilova et al., 2023) and it is commonly referred to as a comprehensive synthesis of the literature (Fetscherin & Heinrich, 2015). Co-citation method is the most frequently employed and validated bibliometric approach (Zupic & Čater, 2015). Establishing connections between documents, authors, or journals through co-citation has proven to be dependable. The data from co-citation analysis can be utilised to assess not only the prominence of specific authors but also the influence of their publications (Ziabina & Pimonenko, 2020; Fahimnia et al., 2015). While co-occurrence is essential for mapping the thematic and conceptual landscape of a research field by analysing how often specific keywords appear together in the literature (Kwilinski, 2024; W. Wang et al., 2023). Co-occurrence of keywords encapsulates the knowledge domains within a particular field of research, defining its boundaries, revealing interconnections, and highlighting trends among research areas (Zupic & Čater, 2015).

Data analysis was carried out using the methodological approach outlined by the authors (Fig. 1), employing excel and the VOSviewer software. VOSviewer is widely used to construct and visualise bibliometric networks based on data from extensive databases like Wos or Scopus (Kwilinski, 2024; Seminario-Córdova & Rojas-Ortega, 2023).

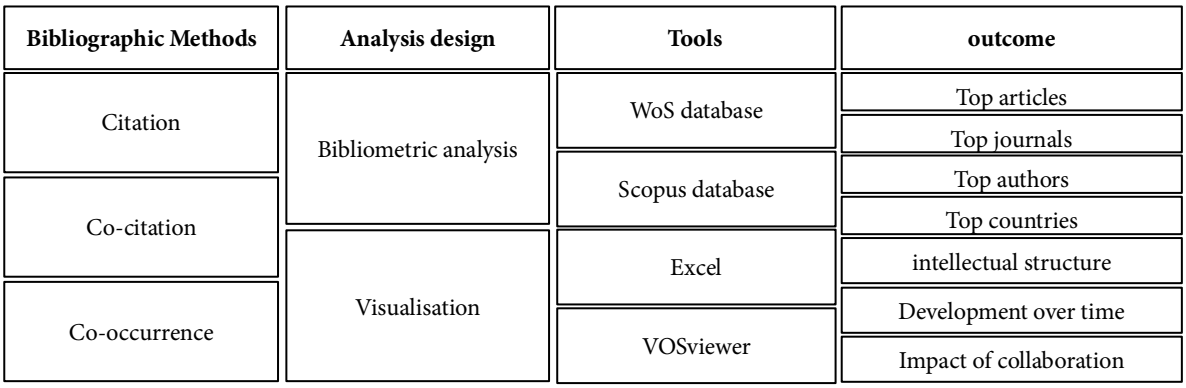

Figure 1. Research methodology.

Source: own elaboration.

3. Research results

3.1 Descriptive analysis

Bibliometric analysis proves to be a valuable method for assessing and scrutinising the outcomes of academic research. It aids in tracking progress, identifying the most dependable sources of scientific publications, establishing an evaluation framework for academic discoveries, recognising noteworthy contributors to scholarly endeavours, and constructing bibliometric indices for assessing academic productivity (Sharma et al., 2022). The total number of 202 articles from WoS and Scopus databases were analysed to determine the characteristics of the sample. The peak of publications paying attention to and analysing the efficiency of investments into renewable energy-based envelopment started in 2021 and about 80% of all articles were published during the past four years (Table 2). It indicates a global response to escalating environmental challenges, with efforts focused on exploring ways to address the impacts of environmental pollution through a shift towards sustainable solutions.

Table 2. Number of articles per year from 2018-2024.

Publication year	WoS		Scopus	
	Articles	% of total articles	Articles	% of total articles
2024	18	19	18	19
2023	19	18	21	22
2022	28	27	25	26
2021	18	17	12	12
2020	8	7	9	9
2019	8	7	7	7
2018	6	5	5	5

Source: WoS and Scopus databases.

China is responsible for over 90 % of the research activity in the respective subject area. China's leading position in research is linked to its role as the world's largest energy consumer, utilising 20% of global energy. Therefore, it emphasises China's crucial involvement in the global transition to sustainable energy. However, with over 60 % of its total energy supply dependent on imports, concerns have emerged about China's energy security and the environmental impact associated with heavy reliance on fossil fuels (Zeng et al., 2018). The statistics on the most active countries, which encompass the number of documents, citations, and total link strength based on VOSviewer summarised data, with a minimum requirement of 5 documents per country, suggested threshold by VOSviewer to keep visualization meaningful and focusing on highlighting most significant trends and connections, revealed that out of the 37 countries analysed, 9 countries from WoS and 6 countries from Scopus met the criteria (Table3).

Table 3. Most active countries.

Country	WoS			Scopus		
	Articles	Citations	Total link strength	Articles	Citations	Total link strength
China	82	2771	101	75	2716	4
Pakistan	12	843	55	8	685	2
United Kingdom	9	219	11	9	213	5
Malaysia	8	766	57	5	748	2
Taiwan	8	72	5	6	71	1
UAE	6	178	21	-	-	-
Vietnam	6	471	42	-	-	-
Japan	5	790	50	-	-	-
South Korea	5	40	2	5	48	0

Source: WoS and Scopus databases.

The leading journals with the highest number of publications are Environmental Science and Pollution Research with 16 publications in total, followed by Sustainability and Economic Change and Restructuring with 17 and 8 publications accordingly. The first free journals cover almost 52% of all publications. The results obtained by setting 3 as the minimum number of documents of a source to get a more comprehensive picture of journals with the highest number of citations (VOSviewer suggesting to use 4 as a minimum number). From the WoS database of the 62 sources, 9 met the thresholds and from the Scopus database of the 65 sources, 8 met the thresholds (Table 4). Notably, it is striking that the most cited journal is Energy Policy with 1533 citations, despite only 6 articles being published in the research area.

3.2 Performance analysis

The performance analysis involved an examination of various networks and the assessment of bibliometric data. Three bibliometric methods (Soliman et al., 2021; Fahimnia et al., 2015) – citation

analysis, co-citation analysis, and co-occurrence analysis – were employed, and each one plays a unique role in bibliometric analysis.

Table 4. Journals with highest number of publications.

Journal	WoS			Scopus		
	Articles	Citations	Total link strength	Articles	Citations	Total link strength
Environmental Science and Pollution Research	10	260	3	6	139	2
Sustainability	10	93	1	7	94	0
Energy Economics	4	171	2	4	190	1
Economic Change and Restructuring	4	142	1	4	169	0
International Journal of Environmental Research and Public Health	3	16	0	4	25	0
Energy Policy	3	728	11	3	805	0
Journal of Cleaner Production	3	320	1	3	447	0
Renewable Energy	4	207	3	4	226	3
Resources Policy	3	138	3	-	-	-

Source: WoS and Scopus databases.

The first two methods utilise citation data to establish measures of influence and similarity which helps to select the most relevant research works (Odilova et al., 2023; Łukasiewicz et al., 2022; Muhuri et al., 2019; Fetscherin & Heinrich, 2015). The third is the method of content analysis that leverages the words found in documents to establish connections and build a conceptual framework within the field (Muhmad et al., 2024; Wang et al., 2023). Kwilinski (2024) and Zupic & Čater (2015) explain that fundamental concept behind this method is that the frequent co-occurrence of words in documents signifies a close relationship between the underlying structures within scientific literature and identifying both emerging research areas and those that are already well-established.

The most cited article by Zhang et al. (2021), with a total of 992 citations in both WoS and Scopus databases, surpasses the citation count of Jiakui et al. (2023) by almost two times. Jiakui et al. (2023) work has been cited 555 times. The third most cited paper is Song et al. (2021) with 463 citations in total. Zhang et al. (2021) examines panel data from 2008 to 2018 for countries involved in the Belt and Road Initiative (BRI) by applying the Generalised Method of Moments (GMM) and Data Envelopment Analysis (DEA) with the goal to evaluate the correlation between R&D public spending, and the aspects of green economic growth and energy efficiency. The research uncovers the simultaneous presence of both composition and technology effects in achieving the goals of green growth. Furthermore, Zhang et al. (2021) underlines that public investment in both green energy technology research and education speeds up the development of the green economy. Jiakui et al. (2023) uses DEA and directional distance function (DEA-DEF) model to address the gap in the existing literature by creating a thorough index for the expansion of green finance and analysing the Total Factor Productivity Growth (GTFP) within the constraints of energy and the environment. Song et al. (2021) applies super-efficiency DEA and a spatial econometric model to assess energy use efficiency in the context of environmental constraints in the east, middle, and west region of China. Wang et al. (2022) study seeks to explore how green financing impacts renewable energy dependence and the transition to renewable energy in E7 countries by employing the combination of Entropy method (EM), grey relational analysis (GRA), and technique for order preference by similarity to an ideal solution (TOPSIS), DEA methods. Other most cited scholars are Zeng et al. (2018), Zhao et al. (2023), Gu et al. (2021), Feng et al. (2022), Wang et al. (2022), Wang & Wang (2022) and all of them employed different variations of DEA in combination with other supportive methodologies (Table 5).

Table 5. Most cited articles.

Document	Title	Cited WoS	Cited Scopus	Total	Methods used
Zhang et al. (2021)	Public spending and green economic growth in BRI region: Mediating role of green finance	472	520	992	Generalised method of moments (GMM), DEA
Jiakui et al. (2023)	Green technological innovation, green finance, and financial development and their role in green total factor productivity: Empirical insights from China	264	291	555	DEA, directional distance function (DEF)
Song et al. (2021)	Impact of green credit on high-efficiency utilisation of energy in China considering environmental constraints	220	243	463	super-efficiency DEA, spatial econometric model
Wang et al. (2022)	Green financing role on renewable energy dependence and energy transition in E7 economies	145	160	305	Entropy method (EM), grey relational analysis (GRA), and technique for order preference by similarity to an ideal solution (TOPSIS), DEA
Zeng et al. (2018)	Investment efficiency of the new energy industry in China	120	134	254	Four stage DEA
Zhao et al. (2023)	Testing green fiscal policies for green investment, innovation and green productivity amid the COVID-19 era	104	126	230	Baker, Chanes, and Cooper's (BSS) DEA
Gu et al. (2021)	The policy effect of green finance in promoting industrial transformation and upgrading efficiency in China: analysis from the perspective of government regulation and public environmental demands	86	91	177	VAR model, super-efficiency DEA, Tobit
Feng et al. (2022)	Nexus between Government spending's and Green Economic performance: Role of green finance and structure effect	62	73	143	DEA, Generalised method of moments (GMM)
Wang et al. (2022)	Research on the impact of green finance and abundance of natural resources on China's regional eco-efficiency	67	74	141	Super-efficiency DEA, Tobit
Wang & Wang (2022)	Research on the impact of green finance on energy efficiency in different regions of China based on the DEA-Tobit model	64	67	131	DEA, Tobit

Source: WoS and Scopus databases.

Co-citation analysis was conducted by employing reference co-citation analysis to determine the links between published articles in selected research areas. The term "co-citation" refers to the frequency with which two units are referenced together, and the more frequently items are cited together, the more likely they are related (Sharma et al., 2022). Representation of co-citation analysis by using full counting method and setting 5 as the minimum number of citations of cited references from WoS resulted in 54 references which met the threshold criteria out of 5284 cited references (Fig. 2). While setting the same parameters for the data from Scopus resulted in only 4 references meeting the threshold of 5260 cited references.

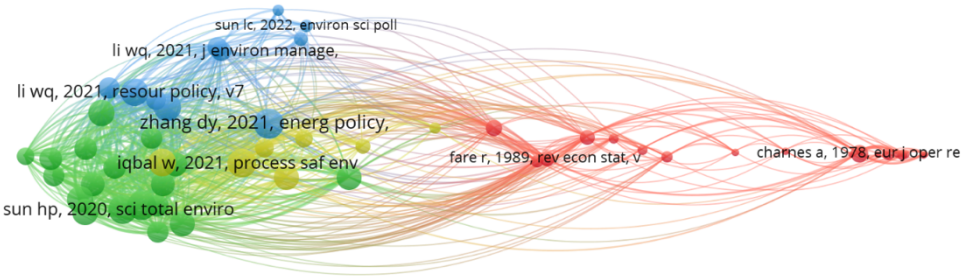

Figure 2. Co-citations of cited references from WoS database.

Source: visualisation by using VOSviewer.

Co-citation analysis disclosed the fact that much more similarity scores between articles, authors, and journals related to renewable energy-based development are among WoS references compared to Scopus. WoS reference total strength link co-citation map (Fig. 2) illustration depicts 4 clusters, each representing a unique thematic focus within the area of investment efficiency into renewable energy-based development. The initial three clusters – cluster 2 (green) comprising 18 items, cluster 3 (blue) containing 10 items and cluster 4 (yellow) containing 7 items – exhibit a notable co-citation strength, suggesting a strong semantic relationship between the items. Sun et al. (2020), Alemzero et al. (2021) and Agyekum et al. (2021) display the highest total link strength, resulting in scores of 164, 157 and 134 respectively, within cluster 2 (green). D. Zhang et al. (2021), Alemzero, Iqbal, et al. (2021) and W. Li et al. (2021) from cluster 3 (blue) display total link strengths of 175, 143, and 142 respectively, and Baloch et al. (2020), Iqbal et al. (2021) and Mohsin et al. (2021) from cluster 4 (yellow) display total link strengths of 158, 154, and 127. Cluster 1 (red) with 19 items which include a significant amount of historical research, dating as far back as 1957 and has much weaker connection to the other clusters, suggests that this is due to potentially outdated and not relevant research information.

Another beneficial aspect in comprehending the research patterns of a specific topic is the identification of co-occurring keywords. When conducting the analysis of co-occurrence of all keywords to determine the relatedness of items based on the number of documents in which they occur together, number 5 was set as the minimum number of occurrences of keywords, which resulted in 31 of 624 keywords meeting a threshold requirement in WoS. Irrelevant words "China" and "impact" were eliminated from keyword co-occurrence network map analysis and visualization (Fig. 3).

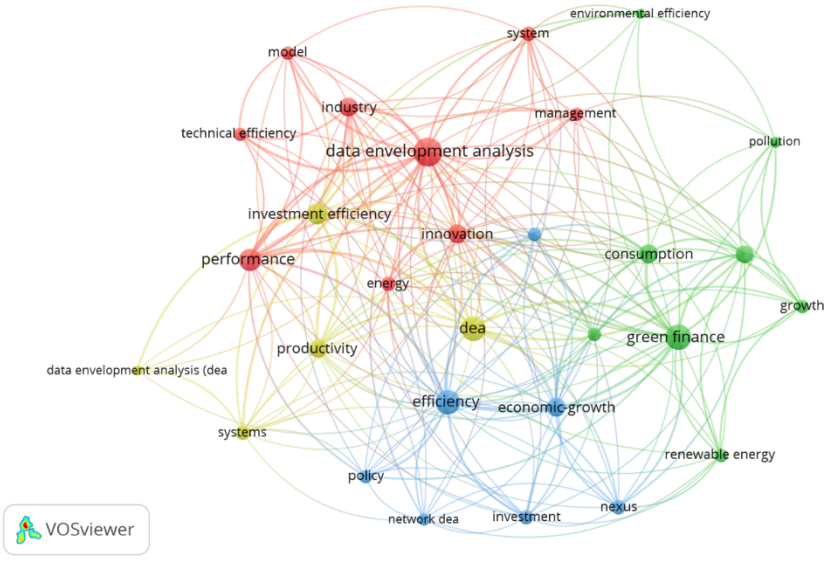

Figure 3. All keyword co-occurrence from WoS.

Source: visualisation by using VOSviewer.

From Scopus database 33 keywords of 850 met a threshold requirement before eliminating irrelevant words "China", "panel data", "article", "human" from keyword co-occurrence network map analysis and visualization (Fig. 4).

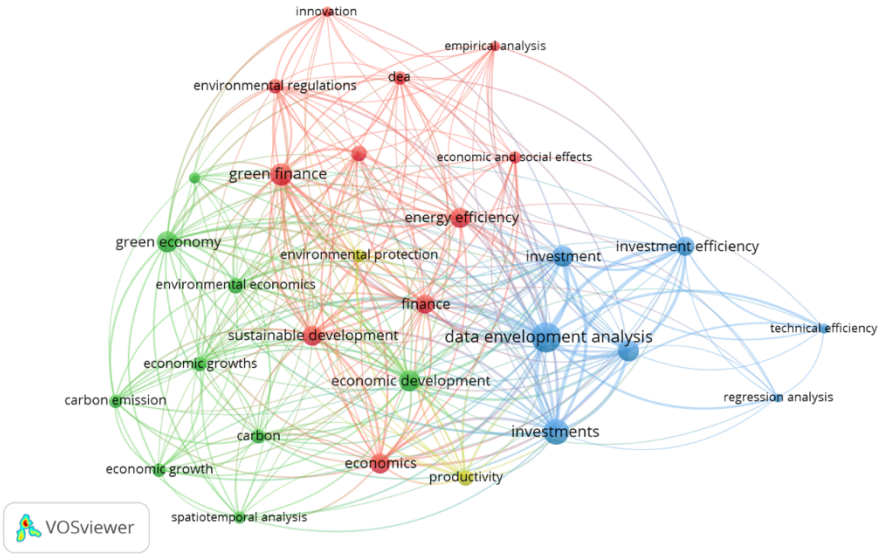

Figure 4. All keyword co-occurrence from Scopus.

Source: visualisation by using VOSviewer.

Employing VOSviewer software for keyword co-occurrence analysis and visualisation facilitated the recognition of groups and domains delineated by distinct colour clusters within bibliometric networks. Upon analysing both databases, a total number of 4 emerging clusters closely interrelated in research on investment efficiency into renewable energy-based development (Table 6). The predominant keyword correlations revolved around DEA and investments, interment efficiency, green finance and energy efficiency. This outcome offers insights into the primary subjects of each cluster and describes meaningful characteristics.

Table 6. Main keywords and primary subject of each Cluster.

Cluster	Colour	WoS		Scopus	
		Main keywords	Primary subject	Main keywords	Primary subject
1	Red	DEA, industry, innovation, model, performance, technical efficiency	DEA, Performance	Green finance, energy efficiency, sustainable development, finance, environmental regulations, economics	Green finance, sustainable development
2	Green	Consumption, pollution, environmental efficiency, growth, renewable energy, green finance	Green finance	Green economy, economic development, environmental economics, carbon emissions	Green economy, economic development
3	Blue	Efficiency, economic growth, investment, sustainability, policy	Efficiency	DEA, investments, investment efficiency,	DEA, investments
4	Yellow	DEA, investment efficiency, productivity, systems	Investment efficiency, DEA	Environmental protection, productivity	Environmental protection

Source: WoS and Scopus databases.

4. Discussion

Ultimately, the study highlights the important role of bibliometric analysis as an invaluable tool for understanding the evolving landscape of academic research. By enabling comprehensive insights, informed decision-making, and the progression of knowledge, it becomes instrumental in propelling endeavours towards a sustainable energy future.

Descriptive analysis underscored the significance of bibliometric methods in assessing and scrutinising academic research outcomes. It's evident that scholarly attention to investment efficiency in renewable energy-based development has escalated, especially since 2021. This surge in publications reflects a global response to environmental challenges, with a focus on sustainable solutions. Environmental Science and Pollution Research emerges as the leading journal focusing on research areas, followed by Sustainability and Economic Change and Restructuring. Notably, Energy Policy stands out as the most cited journal despite having a smaller number of articles.

Performance analysis delves deeper into the research landscape, highlighting key articles and methodologies. Notably, D. Zhang et al. (2021) emerges as the most cited article, offering insights into green economic growth and energy efficiency. In most cited references various methods were employed by different scholars, including Data Envelopment Analysis (DEA), Generalised Method of Moments (GMM), super-efficiency DEA, spatial econometric model, directional distance function (DEF), four-stage DEA, Baker, Chanes, and Cooper's (BSS) DEA, entropy method (EM), grey relational analysis (GRA), technique for order preference by similarity to an ideal solution (TOPSIS), Vector Autoregression (VAR) model, Tobit model, and Common Weight DEA. Co-citation analysis revealed 4 thematic clusters within the literature, with notable associations between publications within 3 clusters with noteworthy items (Alemzero et al., 2021a; Alemzero et al., 2021b; Baloch et al., 2020; Iqbal et al., 2021; Sun et al., 2020; Zhang et al., 2021). Keyword co-occurrence analysis further enriches the understanding, identifying clusters of related keywords such as DEA, green finance, and investment efficiency. These findings provide a nuanced view of the primary subjects and characteristics within the research landscape.

The results have addressed the primary research question: What are the effective models to assess the efficiency of green investment into renewable energy-based development under risk and uncertainty? Bibliometric analysis has revealed that a predominant portion of the research relies on the Data Envelopment Analysis (DEA) method and its variants, often complemented by methodologies such as Tobit, TOPSIS, spatial econometric models, among others. This analysis not only outlines initial research directions but also maps the interconnections and links between published research, demonstrating the diverse combinations of methodological approaches. This comprehensive overview serves to facilitate and guide future research endeavours in the field.

Conclusions

In conclusion, the significance of renewable energy in combating climate change and ensuring a stable energy future has surged, with researchers exploring various dimensions of renewable energy-based development. Green finance has emerged as a crucial area of focus, addressing environmental challenges through financial instruments and strategies. Scholars explore and utilise a diverse range empirical approach, mainly facilitated by DEA method, to assess investments and cooperative efforts aimed at fostering a sustainable future.

The research findings revealed valuable insights through descriptive and performance analyses applied in many similar studies (Kut & Pietrucha-Urbanik, 2023; Seminario-Córdova & Rojas-Ortega, 2023; Sharma et al., 2022), shedding light on the dynamics of academic research in the domain of renewable energy-based development. Abdelmageed & Zayed (2020) propose a similar three-step research process which includes bibliometric research, quantitative and qualitative analysis for critical analysis and future directions.

The study's findings offer valuable insights for shaping future research, policy decisions, and practical applications. By highlighting active countries, key scholars, and leading journals, it underscores the growing global focus on renewable energy investment efficiency, especially since 2021. The prominence of methodologies like Data Envelopment Analysis (DEA) in green finance and energy efficiency research suggests a need for continued exploration and refinement in these areas. For policymakers, the identification of emerging trends and thematic clusters can help prioritise investment strategies and create regulations that support sustainable energy transitions. For practitioners, the study provides guidance on optimising investments and enhancing efficiency, making it a critical resource for advancing green finance and technological innovation.

Bibliometric analysis proves invaluable in uncovering the interconnectedness and thematic trends within the literature on renewable energy-based development and applied empirical methodologies from solid databases. By providing insights into research directions and facilitating future inquiry, these analyses pave the way for continued scholarly advancement in the field.

It is important to note that, despite the extensive literature review based on descriptive and performance analyses, this study has certain limitations. While the bibliometric analysis provides a broad overview, it may not capture all the nuances of the dynamic relationships among DEA, green finance, and investment efficiency. Limitations arise from reliance on existing literature, the choice of databases, and the restricted time frame, which could constrain interpretative possibilities. Additionally, the selection of keywords may influence the scope and quality of the analysis, potentially affecting the generalisability of certain findings.

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