Mapping the Intellectual Structure of Green Bonds Research in Clean Energy Transition

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Research Article

Abstract

Purpose: *Green bonds are designed to provide financial resources for deploying affordable and economically viable carbon-friendly energy infrastructures. This paper discusses the research trends, current practices, and future research implications of green bonds in the clean energy transition.*

Methods: *This study extracted scholarly articles from the Scopus database and used bibliographic analysis to uncover publication trends, research affiliations, geographical contexts, thematic trends, and bibliographic coupling, along with a narrative literature review to assess current practices and pinpoint future research directions for the widespread adoption of clean energy.*

Results: *Developing countries, particularly those in Asia, have a strong research portfolio on financing the energy transition through green bonds. However, financial markets in developing countries are weak and unorganized, hindering the growth of energy-efficient projects. Policy development, focusing on building energy infrastructure, standard reporting frameworks, stringent regulations, and prioritizing investor confidence, is essential for transitioning to a low-carbon economy.*

Implications: *Researchers, regulators, and policymakers can make use of the results of the research questions to develop a unique framework regarding the strategic thinking and actionable development plan of green bonds for any positive impact on energy efficiency*

Originality: *This study employed a systematic, quantitative, and qualitative approach to answer the research questions. The quantitative approach examines the critical areas researchers need to address to support the energy transition through green bond financing. The qualitative approach evaluates the current green bond infrastructure and explores future directions for successfully implementing a renewable energy strategy.*

Keywords: Green Bonds, Clean Energy, Green Energy, Energy Transition, Bibliometric Analysis.

1. Introduction

According to the International Energy Agency (IEA), global energy demand is projected to increase by 25% as the world's population is estimated to grow by 1.7 billion by 2040 (International Energy Agency, 2018). However, this growth in demand must be balanced with reduced fossil fuel consumption and increased use of renewable energy sources. Mobilizing finance to invest in clean energy has become a critical tipping

point for reinforcing a sustainable, eco-friendly green economy (Bhattacherjee et al., 2023). Over the last few years, green bonds have emerged as an efficient financing tool for mitigating global energy transition concerns. While rapid economic growth, rising energy consumption, the Ukraine-Russia war, climate hazards, and environmental damage have posed threats to humanity's development of a low-carbon economy, green bonds aim to provide financial resources to deploy affordable, cost-effective, carbon-friendly energy infrastructure. Financing clean energy has become a concern for climate-resilient development and the fulfillment of the 20230 United Nations Sustainable Development Framework. Many countries are issuing green bonds to reduce CO2 emissions and accelerate environmental progress by focusing on renewable energy.

The nexus between green bonds and the sustainable economy dates back to 2011, when the crucial role of green bonds in shifting the fossil-fuel-based economy toward a greener one was demonstrated to curb the "destination" trend (Mathews, 2011; Saha et al., 2024). Even though the research on green bonds has grown immensely in the last few years, the literature is mostly on stock price connectedness to climate financing (Chatziantoniou et al., 2022; Bhattacherjee et al.,2022), green bonds as an investment hedge (Dong et al., 2023), green bonds' effect on firm bottom line performance (Khurram et al., 2023), green wash practices in green bond investment (Shi et al., 2023), green bond market expectations(Baker et al., 2022), and other related research (Kedia& Joshipura, 2023; Abhilash et al, 2022; Khamis & Aysan, 2022). This study is among the first to focus on the effects of green bonds on the transition to sustainable renewable energy, with implications for future research in business and economics. Most existing studies of our interest are either narrative reviews or quantitative-focused (AIS, 2018; Arif & Sabuj, 2018). This research considers both a quantitative approach of network and cluster analysis of research themes and trends and a qualitative review of the comprehensive understanding of the current state of the literature on green energy transition practices, including drivers, vulnerabilities, and energy infrastructure, to provide a global perspective of green bond literature to finance clean energy. The unique part of this study lies in combining three significant segments of the green bonds research on sustainable energy practices in a single study: research implications, current practices, and future research directions. The findings of this research could provide valuable insights for energy policymakers and help guide future studies in resource allocation, stakeholder engagement, and regulatory frameworks and policies. Previous studies by scholars (Taghizadeh-Hesary et al., 2020; Mohsin et al., 2021) and government reports have highlighted the importance of green finance and energy policy for enterprises and governments. However, implementation of these policies can be challenging. While most literature analyses consider basic characteristics, research hotspots, and development trends according to the number of publications and the frequency of co-occurrence words (Kedia & Joshipura, 2022; Abhilash et al., 2022), we identified four feasible policy segments through clustering analysis: energy infrastructure, regulation, green economy, and investor sentiment. We further outline the existing challenges and future research questions for each policy segment, along with opportunities and risks for the clean energy transition, so that academicians, policymakers, managers, and practitioners can understand the future green bond risks associated with each policy to combat the energy crisis. To capture the essence of emerging research streams, a thorough literature review of the adoption of green bonds for clean energy is necessary to gain insight into the current research landscape and areas warranting further exploration. The paper highlights emerging research trends and promising research directions, such as economic growth, energy efficiency, geopolitical risk, and carbon emission, that could serve as a foundation for future studies and advancements in this field. This insight could prove valuable to researchers by pinpointing underdeveloped areas.

To understand the spectrum between green bonds and clean energy transitions, we review the existing literature to answer the following questions.

> RQ1: What are the primary academic research interests related to green bonds and energy transitions, considering key issues, authors, affiliations, and geographical circumstances?

RQ2: What is the current scenario of green bonds discussed in the literature to facilitate the clean energy transition?

RQ3: What is the future research direction, challenges, and future research questions emerging from green bonds that might affect the course of action of sustainable green energy?

The study makes three key contributions to the scholarly literature. First, its findings could provide valuable insights for energy policymakers and help guide future studies on the management implications, organizational strategy, and economic and financial decision-making policies for the energy transition. We developed four feasible policy segments through clustering analysis: energy infrastructure, regulation, green economy, and investor sentiment. We further outlined the existing challenges and future research questions for each policy segment of the clean energy transition. Second, this paper highlights emerging trends and promising research directions, underscoring their importance. Our thematic study predicts that themes such as green bonds, economic growth, energy efficiency investments, renewable energy, geopolitical risk, carbon emissions, and climate change are highly relevant but need further development. As these areas are currently underdeveloped, they can serve as the foundation for advancements in this field. This insight could prove invaluable to researchers, helping pinpoint underdeveloped areas and guiding future research. Third, the study underlines a notable discrepancy in the actions of developed countries in Europe and North America. Despite their vocal support for clean energy and strong advocacy on climate change, their research contribution to financing the energy transition through green bonds is not as substantial as expected. This discrepancy warrants in-depth research to understand the underlying factors and the formulation of targeted policy frameworks to encourage these nations to amplify their support for green bonds. It is imperative to conduct further research and develop appropriate policy guidelines in these countries to encourage other nations to focus on green bonds, reduce reliance on fossil fuels, and lower carbon dioxide emissions.

It highlights the critical geographic factors, journals, academicians, institutions, publishers, and research areas that are attracting greater attention to address the renewable energy dilemma through green bond financing. This holistic view will facilitate potential researchers in developing new innovative ideas and help streamline research development. Second, this study offers a comprehensive review of the effectiveness of green bonds in financing the transition to an emission-free energy system. This will help investors and marketers overcome existing challenges and barriers to green bonds and build a stronger financial infrastructure to address the global energy crisis. Third, we propose a plan for green bonds that combines future research directions, challenges, and questions warranting further investigation to successfully implement a renewable energy strategy. This future study will aid policymakers in evaluating the ecosystem and identifying opportunities and challenges to allocate resources more effectively.

2. Research Methodology

This study extracted past scholarly articles from the Scopus database on October 25, 2023. Scopus is widely regarded as a trustworthy source for bibliometric data because it is the largest curated abstract and citation database. Its extensive coverage of scientific journals on both a global and regional scale makes it a valuable tool for accurate research (Bhuiyan et al., 2024)

Since this study revolves around two main keywords, green bonds and sustainable clean energy transition, we employed clean, renewable, and green energy to refer to energy transition substances. We used a multipotential mix of Boolean keywords based on title, abstract, and keywords format on Scopus; TITLE-ABS-KEY (("green bond" OR "green bonds" OR "green bond financing") AND ("clean energy" OR "renewable energy" OR "energy efficiency" OR " energy transition" OR "clean energy" OR "green energy")) to produce the primary sample database for this study. The first search yielded 244 documents covering the period between 2012 and 2023.

Topic Identification:
Green Bond and Clean Energy Transition

Database Selection:
Scopus

Articles identified N = 244
TITLE-ABS-KEY (("green bond" OR "green bonds"
OR "green bond financing") AND ("clean energy"
OR "renewable energy" OR "energy efficiency" OR "
energy transition" OR "clean energy" OR "green
energy"))

Articles excluded N = 90
Inclusion Criteria:
Subject Areas: Economics, Econometrics, Finance,
Business Management, Accounting, and Social
Sciences
Time Frame: 2012-2023
Document Type: Article, book chapters, and review
papers
Language: English

Articles identified N = 154
154 relevant articles were selected for further Title and
Abstract screening.

Articles excluded N = 27
27 Articles excluded based on Title and Abstract
screening for green bonds and clean energy transition.

Full Articles identified N = 127
127 relevant articles were selected for full-text screen
screening.

Articles excluded N = 41
Articles excluded based on lack of scope, relevance, and
context.

Final Documents identified N = 86
86 relevant documents were selected for bibliometric
analysis in VosViewer, Biblioshiny R package and
Excel.

Overview of Current practices in green bond
effectiveness on Clean Energy Transition

Future research direction, challenges, and research
questions

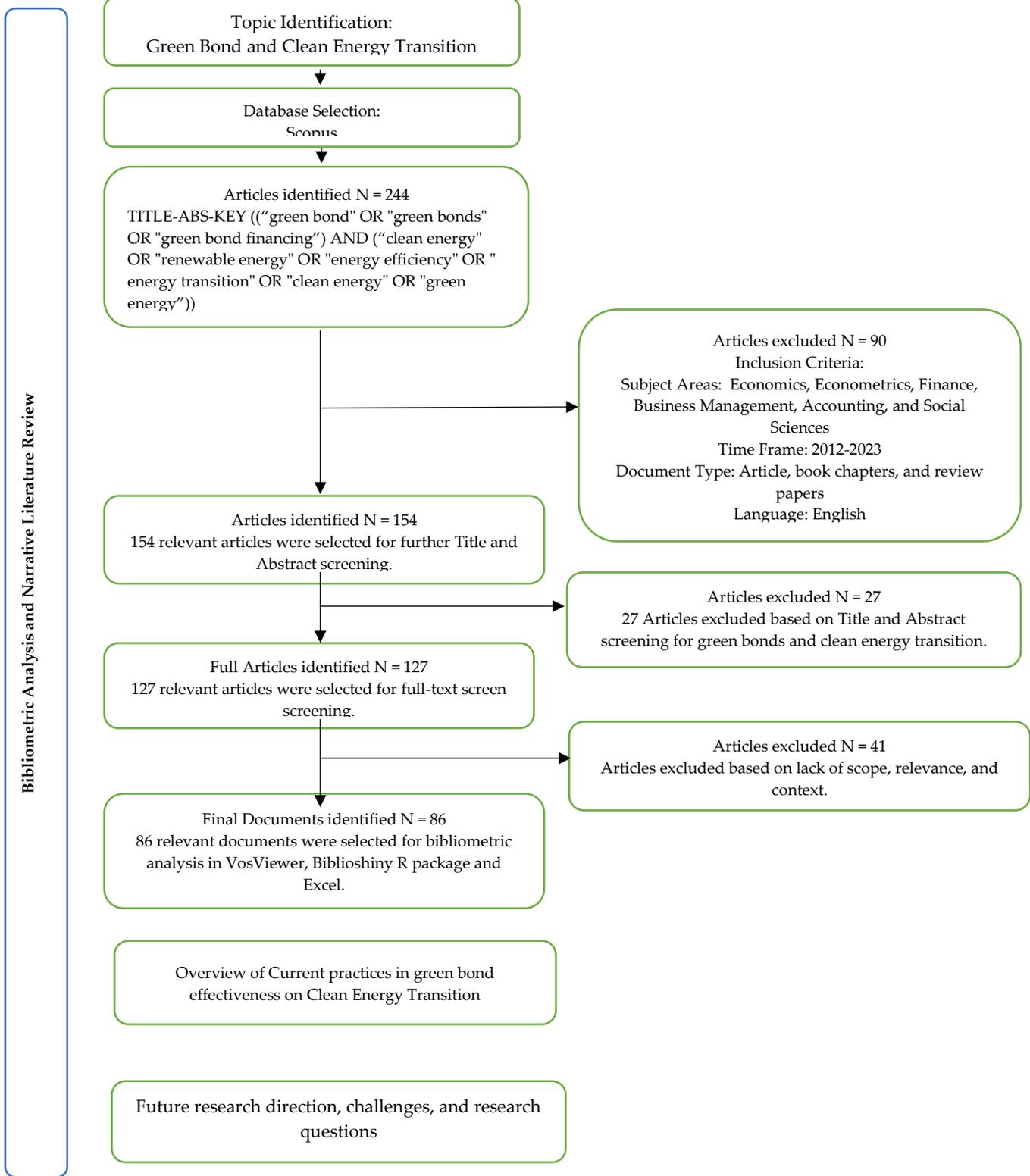Bibliometric Analysis and Narrative Literature Review

Fig 1: Research Methodology (Based on PRSIMA)

We then applied the inclusion and exclusion criteria to our initial search results to identify more relevant scholarly works for the analysis. We filtered our search to subject areas: Economics, Econometrics, Finance, Business Management, Accounting, and Social Sciences. We included journal articles, book chapters, and

review papers in our search and limited our analysis to English-language papers. After applying the inclusion and exclusion criteria, 90 irrelevant studies were excluded, leaving 175 documents for further analysis.

In the next phase, we carefully analyzed each paper's title, abstract, keywords, and conclusion to ensure that any unrelated topics were excluded and that the remaining literature closely aligned with the theme of green bonds and renewable energy research. In this process, we removed 27 documents to improve the sample for research findings.

In the final stage, we conducted a full-text screening of the remaining documents to ensure they remained relevant to the study's course. We reviewed each article individually and scored it 0 if it was out of scope or did not fit the framework of our study. Most of the discarded articles address the price relationship between the green bond market and other markets, methods for estimating green bond prices, green bonds as a hedge for investments in other assets, and the COVID-19 impact on green bonds. The objective is to include documents on green bonds to invest in clean energy solutions. This evaluation process has led to 86 documents we considered for final analysis.

To examine the scientific study of 86 documents on green bond financing for the energy transition, this study has adopted bibliometric analysis. A bibliometric study is an essential and effective tool to highlight a particular research field's development trajectory and distinctive features (Mourao & Martinho, 2020). Its use can provide valuable insights into the field's evolution and help identify areas that require further investigation. This approach can revolutionize the review process for science and scientific activity by utilizing statistical measurement. It offers a systematic, transparent, and reproducible method that could significantly impact how we evaluate science and scientists. This technique examines a field's structures, identifies key research elements, highlights gaps, generates innovative ideas, and positions researchers to contribute to their discipline (Saha et al., 2024; Yesmin et al., 2019).

We deployed VOSViewer, Biblioshiny R package, and Microsoft Excel software to analyze our bibliographic review. The VOSviewer shows network analyses, such as bibliographic coupling and co-citation networks, as well as keyword co-occurrence of green bonds with clean energy (Islam et al., 2024). At the same time, the Biblioshiny R package and Excel help analyze publication trends, sources, university affiliation, and countries' engagement in financing clean energy through green bonds.

We also conducted a comprehensive review of the existing literature to examine current practices and scenarios for financing renewable energy growth through green bonds. We followed a more narrative approach to the literature review to assess the effectiveness of green bonds for energy solutions and to pinpoint future opportunities and threats for rolling out widespread clean energy use. Adding a qualitative narrative approach alongside a quantitative bibliographic method provides a more robust understanding of the role of green bonds in clean energy and enhances the reliability and credibility of the study.

3. Bibliometric Analysis
3.1 Summary Statistics
Table 1 shows that the data for the research were collected from 2012 to 2023. There are 50 sources, 86 documents, and 288 authors. Of 86 documents, 11 are single-authored. The document covers 4338 references and 241 keywords. The average number of citations per document is 24.47. The table also shows that 48.84% of co-authorships are international, the co-authorship per document is 3.74, and the annual growth in scientific production is 39.52%. This research covers 79 articles, 6 book chapters, and 1 review paper.

Table 1: Summary Statistics

Description	Results
MAIN INFORMATION ABOUT DATA	
Time span	2012:2023
Sources (Journals, Books, etc.)	50
Documents	86
Annual Growth Rate %	39.52
Document Average Age	1.27
Average citations per doc	24.47
References	4338
DOCUMENT CONTENTS	
Keywords Plus (ID)	479
Author's Keywords (DE)	241
AUTHORS	
Authors	288
Authors of single-authored docs	11
AUTHORS COLLABORATION	
Single-authored docs	11
Co-Authors per Doc	3.74
International co-authorships %	48.84
DOCUMENT TYPES	
article	79
book chapter	6
review	1

3.2 Publication Over Time

Fig. 2 shows that the number of documents published through 2019 was minimal. However, since 2019, publication volume has grown rapidly, reaching a peak in 2023, demonstrating that green bonds have become increasingly popular for clean energy finance.

Fig.2: Publication Over Time

In the last five years, from 2019 to 2023, the number of publications has increased nearly 20 times. The steep increase in green bond issuance suggests that green bonds are increasingly attracting investors and that we can use them to address the challenge of the energy transition.

3.3 The Most-Cited Publications

Using the Scopus index statistics database, we have compiled a list of the top ten most-cited articles for evaluating the work of the writers in Table 2. The most-cited publication is "Carbon emissions across the spectrum of renewable and nonrenewable energy use in developing economies of Asia" in 2019 followed by "Dependence and risk spillovers between green bonds and clean energy markets" in 2021 and "Dynamic spillover effects among Green Bond, renewable energy stocks and carbon markets during COVID-19 pandemic: Implications for hedging and investments strategies" in 2022. The Journal of Cleaner Production published two highly referenced articles in 2019. Among the top 10 journals, Tolliver C., Keeley A.R., and Managi S. published two papers on our list.

Table 2: The Most-Cited Publications

Authors	Title	Year	Source Title	Total Citation
Hanif I.; Aziz B.; Chaudhry I.S.	Carbon emissions across the spectrum of renewable and nonrenewable energy use in developing economies of Asia.	2019	Renewable Energy	141
Liu N.; Liu C.; Da B.; Zhang T.; Guan F.	Dependence and risk spillovers between green bonds and clean energy markets	2021	Journal of Cleaner Production	118
Tiwari A.K.; Aikins Abakah E.J.; Gabauer D.; Dwumfour R.A.	Dynamic spillover effects among green bond, renewable energy stocks, and carbon markets during the COVID-19 pandemic: Implications for hedging and investment strategies	2022	Global Finance Journal	114
Hammoudeh S.; Ajmi A.N.; Mokni K.	Relationship between green bonds and financial and environmental variables: A novel time-varying causality	2020	Energy Economics	108
Ng T.H.; Tao J.Y.	Bond financing for renewable energy in Asia	2016	Energy Policy	95
Tolliver C.; Keeley A.R.; Managi S.	Policy targets behind green bonds for renewable energy: Do climate commitments matter?	2020	Technological Forecasting and Social Change	93
Zhao L.; Chau K.Y.; Tran T.K.; Sadiq M.; Xuyen N.T.M.; Phan T.T.H.	Enhancing green economic recovery through green bonds financing and energy efficiency investments	2022	Economic Analysis and Policy	91
Ferrer R.; Shahzad S.J.H.; Soriano P.	Are green bonds a different asset class? Evidence from time-frequency connectedness analysis	2021	Journal of Cleaner Production	90
Tolliver C.; Keeley A.R.; Managi S.	Green bonds for the Paris Agreement and Sustainable Development Goals	2019	Environmental Research Letters	83
Azhgaliyeva D.; Kapoor A.; Liu Y.	Green bonds for financing renewable energy and energy efficiency in South-East Asia: a review of policies	2020	Journal of Sustainable Finance and Investment	80

3.4. University Affiliation

Fig. 3 illustrates the top article affiliations of the publication. Central South University, Hasan Uddin University, and Tokai University each published 6 articles, followed by China University of Mining and Technology, Esch-Sur-Alzette, and Qingdao University, which each published 5 articles. The University of Tehran contributed 4 articles. Each of the other universities in the following diagram has published 3 articles.
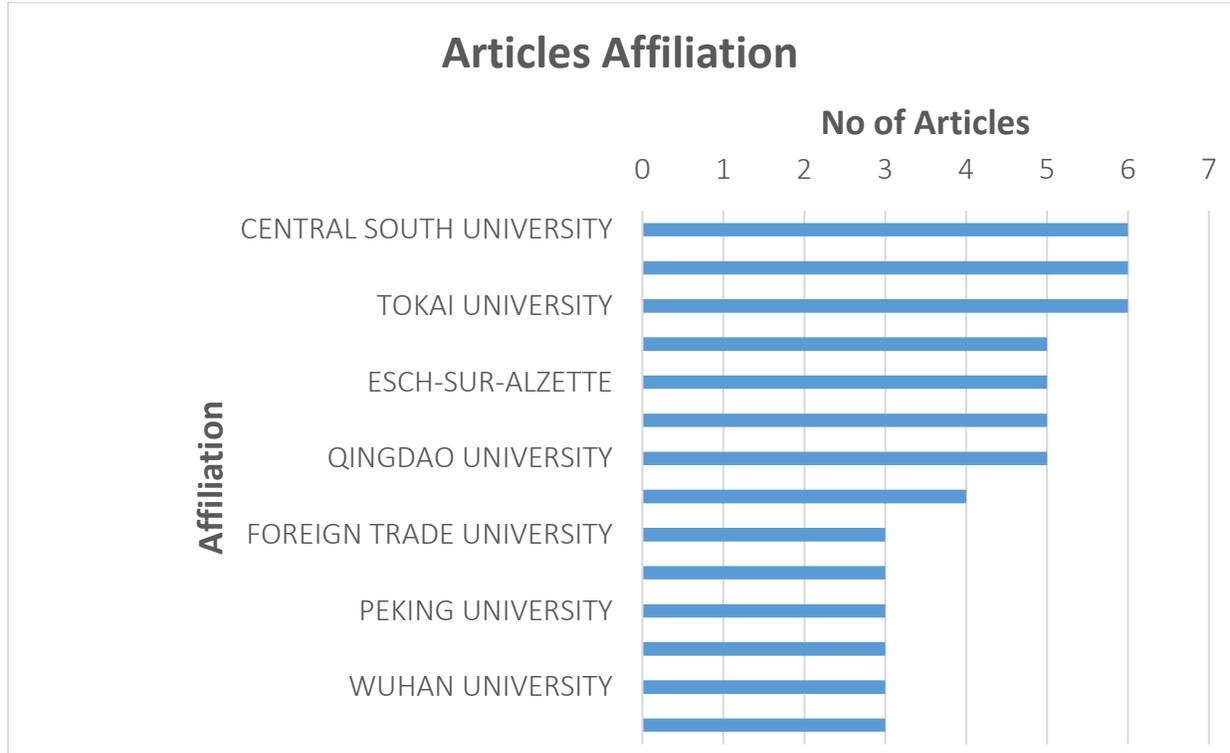

Fig. 3: Article Affiliation

3.5 Country Collaboration, Country Publication, Country Citation, Country Collaboration MAP, and Country Co-Authorship

3.5.1 Author's Country Collaboration

Fig. 4 shows the author's collaboration among countries based on single-country publications (SCP) and multiple-country publications (MCP). China plays a significant role in SCP, or intra-country, and MCP, or inter-country, article collaboration. It shows that China has emphasized research collaboration on green bonds to address its own energy crisis and has also extended this collaboration to other countries. Compared with China, the contributions of other countries are negligible. Nevertheless, Japan, Pakistan, France, Iran, and Australia played a role in SCP and MCP. Singapore, Austria, Bangladesh, Canada, Hong Kong, India, and Indonesia concentrated research on cross-country affiliation, whereas Germany remained with SCP.

3.5.2 Countries, Publications, and Citations

Table 3 presents the top countries in green bonds and clean energy research, ranked by the number of articles and citations. China has the most published articles and the most citations. The remaining countries fall far behind China regarding the number of publications and citations. Australia, Japan, the UK, and Pakistan stand in the top 5 in published papers. Pakistan, Singapore, Japan, and India are in the top 5 in citations.
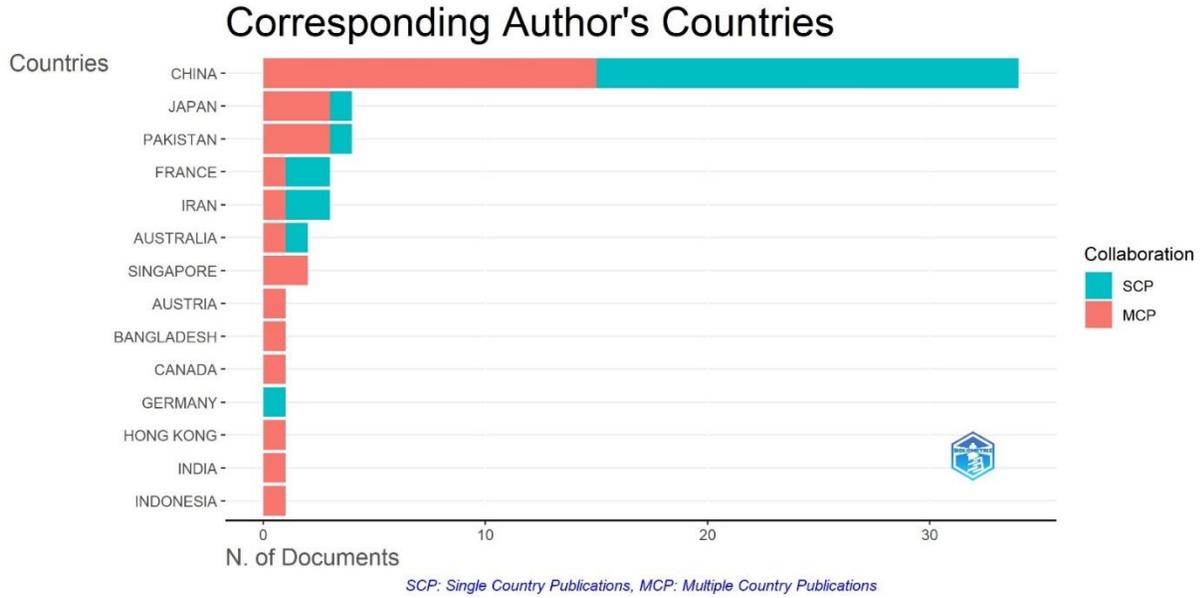
Corresponding Author's Countries

Fig. 4: Country Collaboration

Although developed countries are expected to contribute much more to green bond research, given their greater research funding and financial infrastructure, the table shows that both developed and developing nations have similar research profiles and outcomes, as measured by publications and citations.

Table 3: Countries, Publications, and Citations

Country	Articles	Country	Citation
CHINA	101	CHINA	484
AUSTRALIA	20	PAKISTAN	240
JAPAN	15	SINGAPORE	175
UK	14	JAPAN	164
PAKISTAN	12	INDIA	114
INDONESIA	11	USA	108
INDIA	8	FRANCE	67
USA	8	IRAN	65
FRANCE	7	KAZAKHSTAN	30
BANGLADESH	5	LUXEMBOURG	30
BRAZIL	5	BANGLADESH	27
GERMANY	5	ITALY	27
IRAN	5	AUSTRALIA	23
JORDAN	5	UNITED KINGDOM	23
LUXEMBOURG	5	NORWAY	19

3.5.3 Country Collaboration Map

Fig. 5 presents the country collaboration map, showing the authors' affiliations across countries. The color intensity indicates the number of publications in a country, and the thick line shows the frequency of collaborations. We noticed three strong collaborations between countries: China and Pakistan- 6 articles; Japan and China – 5 articles; and the UK and Australia - 3 articles stand out as the top collaborating countries. We also found a few collaborations between authors from two countries, including the USA and Germany (2 articles), India and Sweden (2 articles), and the UK and Ghana (2 articles).
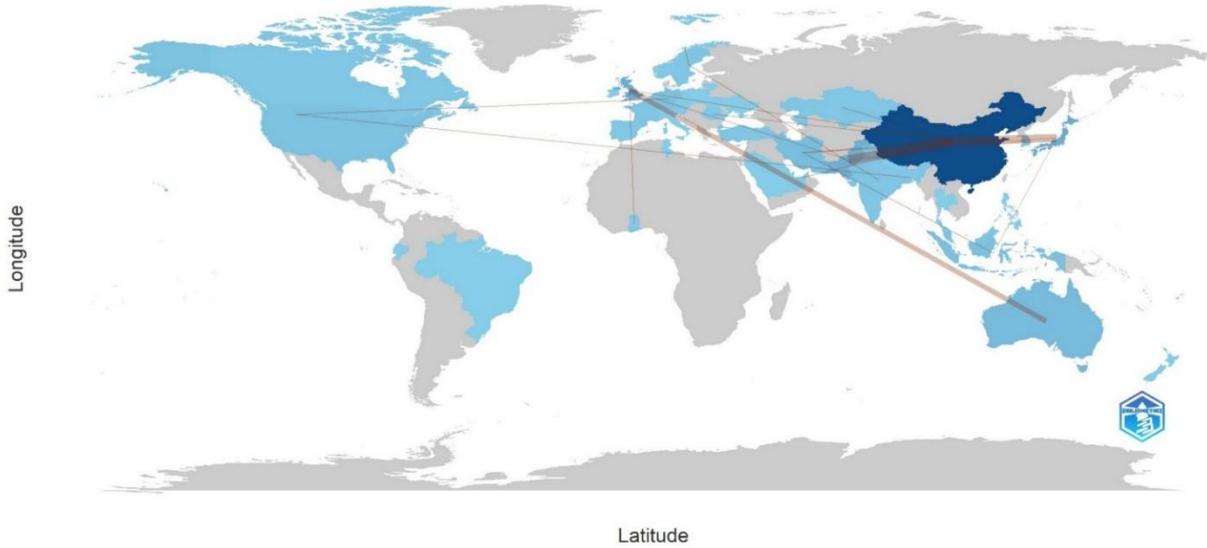
Country Collaboration Map

Fig. 5: Countries Collaboration Map

3.5.4 Co-authorship of Countries

Fig. 6 depicts the co-authorship among countries. The countries to be included in the analysis were defined in three documents. Therefore, of the 55 countries, only 20 meet the requirement. These 20 countries are grouped into 4 clusters with 69 links and a total link strength of 103.
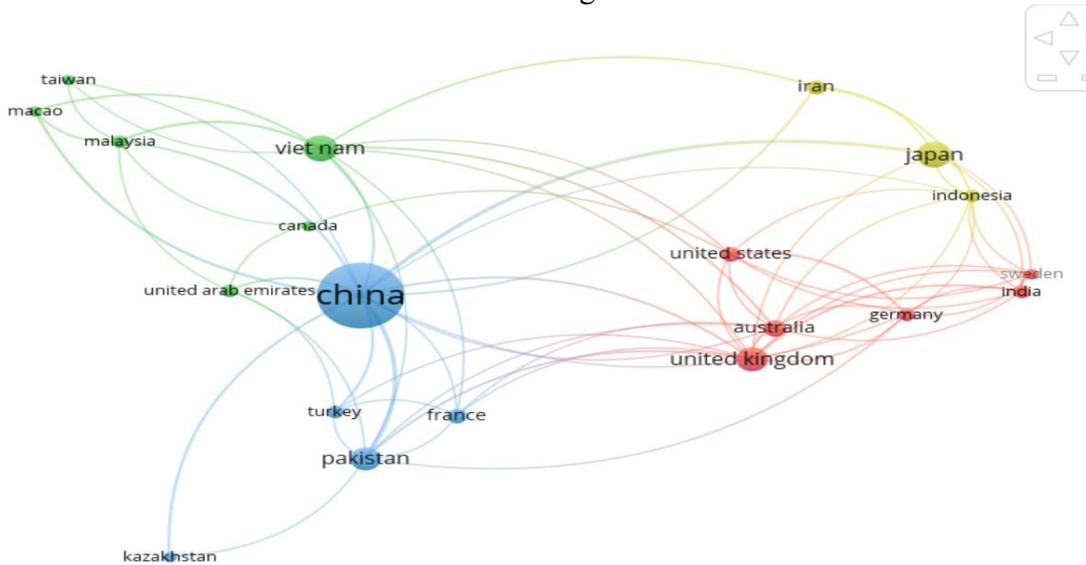

Fig. 6: Co-authorship of Countries

Cluster 1 is colored red and contains six countries: the UK, Australia, Germany, the USA, India, and Sweden. Cluster 2 is colored green and contains six countries: Vietnam, the UAE, Canada, Malaysia, Taiwan, and Macao. Cluster 3 is colored blue and contains 5 countries: China, Pakistan, France, Turkey, and Kazakhstan. China holds the dominant position in cluster 3 and accounts for the greatest co-authorship. Cluster 4 is colored yellow and contains three countries: Japan, Iran, and Indonesia.

3.6. Article Sources

Table 4 presents the top sources for the articles, ranked by the number of publications associated with h-index, g-index, total citations, publication start year, and affiliation. Environmental Science and Pollution Research is the leading journal publisher in green bond research for green energy solutions, with an h-index of 4 and a g-index of 8. It published the highest number of 8 papers, followed by Renewable Energy with 7 papers, with an h-index of 4 and g-index of 7, and Energy Economics in third with 6 papers, with an h-index of 4 and g-index of 6. Journal of Cleaner Production and Resources Policy each published 5 papers. Regarding citations, the Journal of Cleaner Production received the most citations (285), followed by Renewable Energy (199), Energy Economics (176), and Environmental Science and Pollution Research (123). The oldest journal in our research sample was Renewable Energy, which was published in 2019.

Table 4: Article Sources

Sources	h-index	g-index	TC	NP	PY_start
ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	4	8	123	8	2022
RENEWABLE ENERGY	4	7	199	7	2019
ENERGY ECONOMICS	4	6	176	6	2020
JOURNAL OF CLEANER PRODUCTION	5	5	285	5	2021
RESOURCES POLICY	2	5	91	5	2022
SUSTAINABILITY (SWITZERLAND)	2	3	11	4	2022
CHINA FINANCE REVIEW INTERNATIONAL	2	2	57	2	2022
ECONOMIC RESEARCH-EKONOMSKA ISTRAZIVANJA	2	2	22	2	2022
ENERGIES	2	2	22	2	2021
ENERGY	2	2	30	2	2022

3.7 Authors' Articles and Authors' Citation:

Table 5 shows the top authors, their h-index and g-index, the number of publications, total citations, average citations per publication, publication start year, and their affiliations. Among the authors in the list, Taghizadeh-Hesary F. published a maximum of 6 papers on green bonds for energy transition with an h-index of 4 and g-index of 6, followed by Rasoulinezhad E. and Li Y. Each published 4 papers, but Keeley AR and Managi S coauthored the same publications and published the oldest paper on the list in 2019. Keeley AR and Managi S received the highest number of citations (176) and ranked first, with an average of 209 citations per paper.

Table 5: Authors' Articles and Authors' Citation

Authors	Affiliations	h-index	g-index	TC	NP	AC	PY Start
RASOULINEZHAD E	Department of Russian, Caucasus and Central Asian Studies, Faculty of World Studies, University of Tehran	4	4	131	4	32.75	2022
TAGHIZADEH-HESARY F	Dept of Economics, School of Global Studies, Tokai University, Kanagawa, Japan	4	6	105	6	17.5	2022
LI Z	School of Digital Commerce, Zhejiang Yuexiu University, China	3	3	92	3	30.6	2022
KEELEY AR	Department of Civil Engineering, Kyushu University, Fukuoka, Japan	2	2	176	2	88	2019
LI J	School of Business, Central South University, Hunan, 410083, China	2	2	120	2	60	2022
LI N	Key Laboratory of Ocean Energy Utilization and Energy Conservation of the Ministry of Education, Dalian University of Technology, Dalian, China	2	2	72	2	36	2022
LI Y	Hunan University of Technology and Business, China	2	4	54	4	13.5	2022
LIU Y	School of Economics and Management, Wuhan University, Wuhan, China	2	2	97	2	48.5	2020
MANAGI S	Department of Civil Engineering, Kyushu University, Fukuoka, Japan	2	2	176	2	88	2019
PHAN TTH	Faculty of Accounting & Auditing, Foreign Trade University, Viet Nam	2	2	94	2	47	2022

3.8 Keyword Occurrence and Keyword Co-occurrence
3.8.1 Keyword Occurrence
Fig. 7 highlights the frequency of keywords in a paper in the green bond and energy crisis research spectrum.
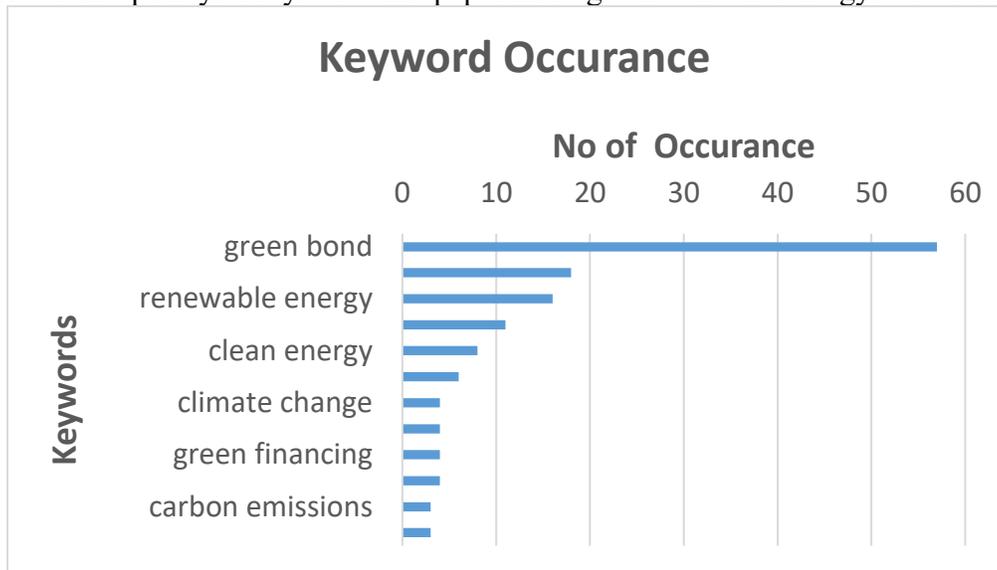

Fig. 7: Keyword occurrence

As expected, the keyword "green bond" has occurred most often, with more than 57 occurrences. Compared to the green bond keyword, the other keywords have been found to a limited extent. In many research studies, green finance, used interchangeably for green bonds, has been found 18 times. Keywords associated

with the clean energy transition are among the top 5. Renewable energy, energy efficiency, and clean energy rank 3rd, 4th, and 5th, respectively, and have occurred 16, 11, and 8 times, respectively. The frequency of other keywords is less than 7 times.

3.8.2 Keyword Co-occurrence

Fig.8 illustrates the keyword co-occurrence analysis. We have 241 keywords in the methodology. The threshold for including keywords in the analysis was determined based on three documents. Therefore, of the 241 keywords, only 18 meet the requirement. We classified these 18 keywords into 4 clusters with 54 links and a total link strength of 113. Cluster 1, colored in red, contains 7 items: climate finance, COVID-19, energy efficiency, environmental finance, green bond, green financing, and sustainable development. The word "green bond" is the most popular, occurring 57 times uniquely in cluster 1 and totaling 63 link strengths. Cluster 2, colored in green, contains 5 items: climate change, geopolitical risk, green finance, innovation, and sustainable development growth. Green finance is the most popular word, occurring 18 times uniquely in cluster 2 with 25 total link strengths. Cluster 3 is colored blue and contains 3 items: carbon emissions, economic growth, and renewable energy. Renewable energy is the most occurring word, 16 times uniquely in cluster 3, with 27 total link strengths. Cluster 4, colored in yellow, contains 3 items: clean energy, digital finance, and sustainable finance. Clean energy is the most common word, 8 times uniquely in cluster 4, with 13 total link strengths.
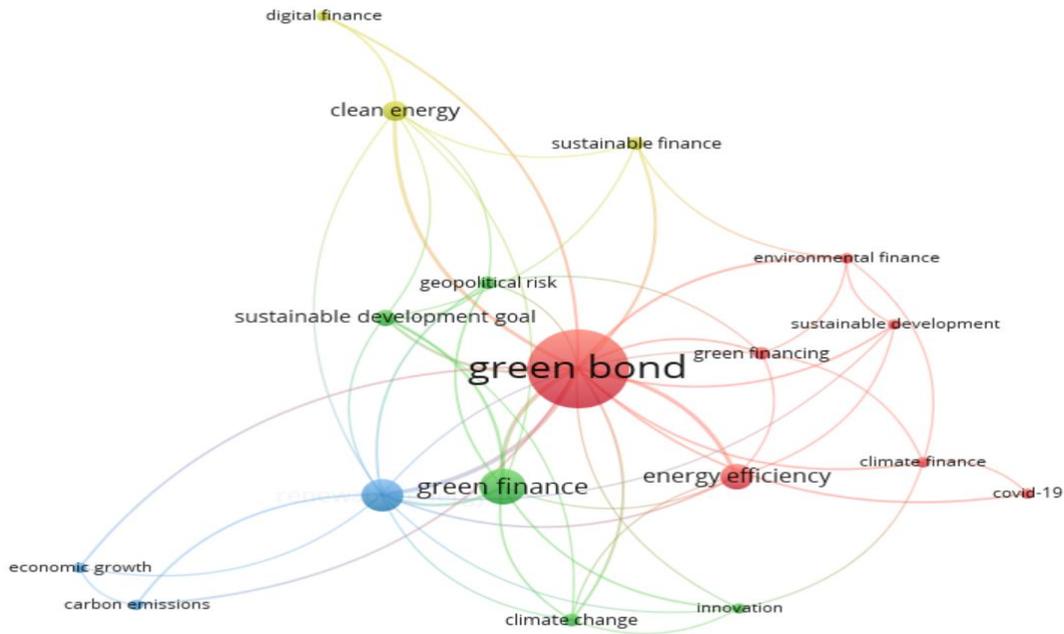

Fig. 8: Keyword Co-occurrence

3.9 Thematic Map

Fig. 9 presents a thematic map summarizing the research agendas of green bonds and the renewable energy transition by density and centrality (Alsmadi et al., 2023).

Motor themes: Motor themes are central and significant, including green financing, sustainable development goals, climate finance, COVID-19, and dynamic connectedness. They highlight that climate finance is becoming prominent in green bonds.

Basic themes: Basic themes include green bonds, economic growth, energy efficiency investment, renewable energy, geopolitical risk, carbon emissions, and climate change. As these are not well developed, they can be included in future research.

Niche themes: These themes are technical and well-developed for the research area. The field includes environmental finance, sustainable development, green energy, energy efficiency, ASEAN, and causality.

Emerging or Declining Themes: This suggests that sustainable finance, clean energy, and digital finance are potential areas for study, or that authors are losing interest in these themes. This quadrant suggests the authors may be interested in, or indifferent to, studying the interlinkages among clean energy, digital finance, and sustainable finance.

Fig. 9: Thematic Map

3.10 Bibliographic coupling

Fig. 10 represents a bibliographic coupling analysis of the author's network.
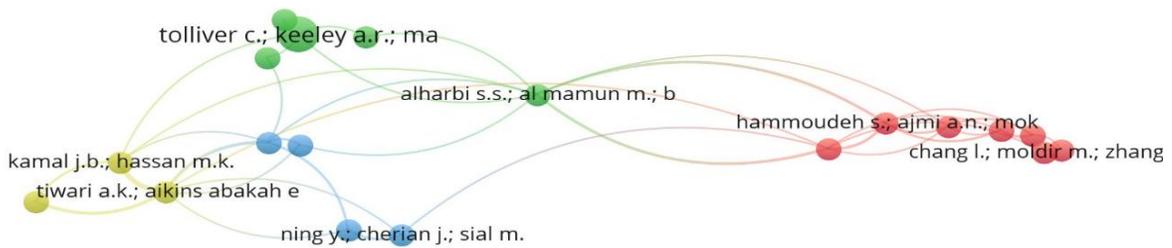

Fig. 10: Authors' Bibliographic Coupling

For the analysis, 85 authors were initially selected. We require at least 1 document per author for inclusion in the analysis, and the minimum number of author citations is 30. Finally, 19 authors were selected and divided into 4 clusters. Cluster 1, colored in red, contains 7 authors; Cluster 2, colored in green, contains 5

authors; Cluster 3, colored in blue, contains 4 authors; and Cluster 4, colored in yellow, contains 3 authors. From the graph, we noted that Keeley is the most productive author in the green bond research sector. The interlinkages among the authors in Cluster 1 are much more robust than those of the others.

3.11 Three-Field Plot

Fig. 11 shows the links among countries, keywords, and sources. The countries' names are presented on the left side, sources in the middle, and keywords on the right. We noticed that China is the most significant contributor in this research area, whose publications are linked to several journals, including "Renewable Energy", "Environmental Science and Pollution Research", "Resource Policy", "Energy Economics", "Sustainability (Switzerland)", "Journal of Cleaner Production" And "Energy". The positions of other countries are significantly different from China's. Pakistan and Japan are ranked second in this field. Meanwhile, the concentration of Pakistan is found in "Renewable Energy" and "Environmental Science and Pollution Research", whereas Japan's concentration is distributed across several journals. Jordan and Luxembourg have been publishing their studies in "China Finance Review International" and "The International Journal of Energy Economics and Policy," respectively, and their choices have remained the same over time. Again, *green bond* and *green finance* are the most popular keywords, followed by *renewable energy, energy efficiency, and clean energy.*
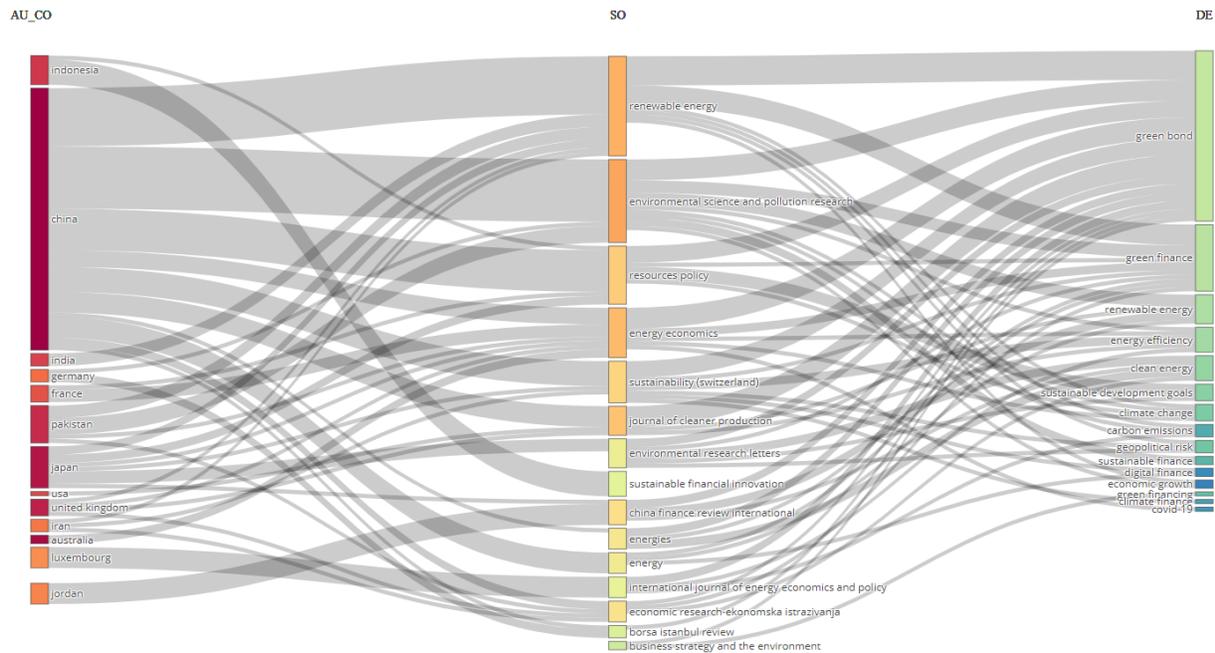
Fig. 11: Three Field Plot

3.12 Factorial analysis

Fig. 12 represents the outcome of the factorial analysis of green bonds for energy transition into two clusters. These clusters have identified and grouped the keywords used by the author in their study, thereby presenting the theme here. We have marked the red cluster as Cluster 1 and the blue cluster as Cluster 2.
 Cluster 1 contains words such as commerce, geopolitics, investments, finance, green bonds, energy policy, innovation, climate change, environmental protection, sustainability, sustainable development goals, COVID-19, economic development, economic growth, carbon emissions, and carbon dioxide, reflecting

green bonds for sustainability. Major themes found in cluster 1 revolve around sustainability, investor influence, and carbon emission.

Cluster 2 contains words such as financial market, clean energy, energy market, and price dynamics, with a focus on clean and green energy. Clean energy dominates all other market sectors, and movement in the clean energy market has a spillover effect on these markets. Green bonds help ensure sustainable economic growth. However, the benefits of green bonds are lost due to the volatility of oil prices. Oil prices significantly impact the global economy and the environment; therefore, practitioners often focus on the relationship between oil prices and green bonds.

Fig. 12: Factorial Analysis

4. Current Practices in Green Bonds for Sustainable Clean Energy Transition

The Paris Agreement goal of limiting global warming to 1.5°C is hard to achieve within the current fossil fuel-reliant energy infrastructure. However, significant investments are necessary to transition to a cleaner energy infrastructure (Climate Bonds Initiative, 2022), and the public and private sectors have been leveraging various financial instruments and mechanisms to achieve that goal. Green bonds have become a prominent tool for funding projects that directly support climate initiatives and conservation.

Fig 13 shows the massive gap between the funding required to fight climate change and the funding available. Traditional policies and structures are geared towards the fossil fuel industry, and factors such as pushback from the private sector due to their assessment of low returns from renewable investments, the need for higher investment and longer projects, and the lack of common frameworks contribute to this gap (Hafner et al., 2020). Despite these hurdles, the green bonds market has grown since its inception, but in 2022, it experienced its first contraction. However, the market is expected to pick back up in 2023 (BNP Paribas, 2023). Given the recent market contraction and the vast funding gap to achieve emission goals, it is prudent to reevaluate the future of the green bonds market to fund the transition of energy infrastructure.

4.1 Energy Infrastructure Transition and Green Bonds

The energy industry has been at the forefront of this discussion as a significant contributor to global warming, and the depleting sources of fossil fuels have led to the discussion about transitioning away from fossil fuel-reliant energy infrastructure. However, it comes with a hefty cost, estimated at $62 trillion worldwide (Jacobson et al., 2022), and the timeline to mobilize this vast sum is by 2050, preferably before 2035. One instrument that emerged to address the costs of transitioning to clean energy and combating climate change is green bonds (Schumacher et al., 2020). However, moving away from an infrastructure

that has taken decades to build is always challenging, and it involves risks. Besides the obvious costs of building infrastructure, the supply chain, and jobs related to those industries, there are additional financial risks, as investors who hold fossil fuel energy assets stand to incur losses (Preclaw & Bakshi, 2015). While the Paris Accord did achieve its short-term targets by addressing systemic market risks (Pham et al., 2019) and ushering in policy changes, the inception of green bonds predates it. The transition away from regular fossil fuels is still in its nascent stage in many parts of the developing world, and the small green bond market in these places means that financing green projects cannot be secured as quickly as in developed countries. However, the issue with using green bonds to finance the energy transition is not due to a lack of investor interest or capital disbursement, but to a lack of standard guidelines, as described in the following sections.
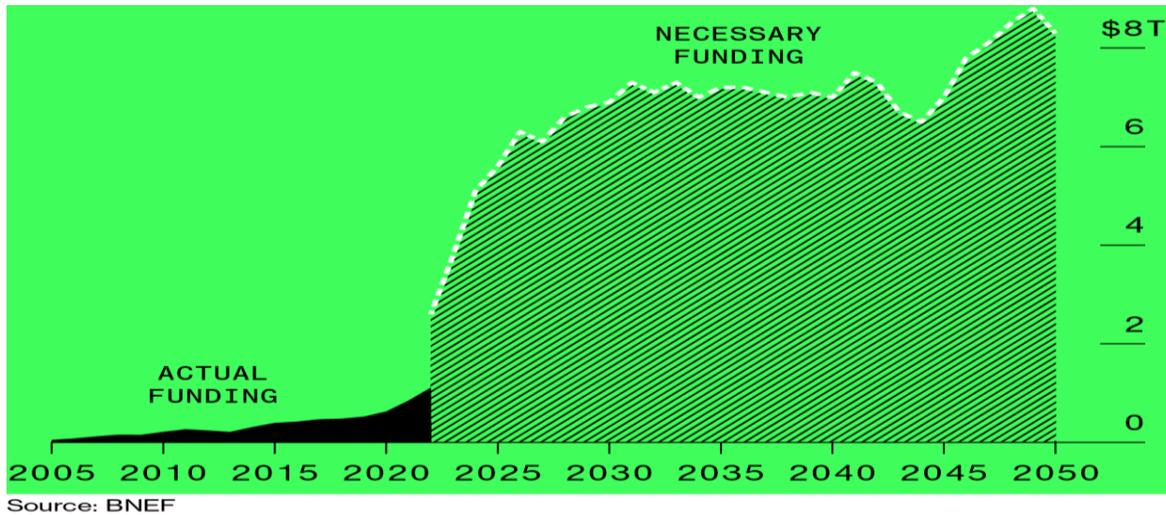
Fig 13: Climate Funding Gap
Source: Bloomberg NEF

4.2 Green Bonds Characteristics and Vulnerabilities for Renewable Energy Projects

Instead of a uniform standard across the board, green bonds have different standards based on region and adoption, like the Green Bond Principles (GBP) and Climate Bond Standards (CBS) in Europe. Countries like China, India, and the US have also opted to have their standards within domestic markets (Baker et al., 2018; Ehlers & Packer, 2016). Due to the flexibility and lack of standardization in the green bonds market, third-party verifiers are used when issuing green bonds (Tang & Zhang, 2020). This additional cost of issuance for green bonds results in lower yields than for a regular bond of similar characteristics (a phenomenon known as the "Green Premium") (MacAskill et al., 2021). On top of that, "Greenwashing "attempts by dubious issuing companies to use the public sentiment toward climate change to raise capital for projects that have nothing to do with green projects. Such attempts are not unforeseen, as all new products and technologies go through a period of tribulation when others try to mimic their success or appeal with inferior alternatives or, as in the case of green bonds, false promises. The need for more reliable data on climate risk and a standard definition of green bonds make it difficult for green bonds to become a truly global instrument while addressing the global challenge of transitioning to clean energy. Renewable energy projects in developing countries will ramp up to meet their energy demands, but investors from Europe and the US might not be willing to invest in the GB issued by those projects due to a lack of data and joint agreements.

4.3 Driving Green Bonds Investments for Cleaner Energy

With investors willing to oversubscribe to green bonds at a premium and the ever-increasing concern about climate change, one would expect the green bond market to grow exponentially. However, corporate green bonds account for only 6% of the global corporate bond market (Carmichael & Rapp, 2022). Researchers have identified certain factors that act as barriers to the green bonds market's growth, but the drivers behind its growth remain vague. Drivers related to the macroeconomic and institutional environment have been found to positively impact green bond issuance volume, as have unique drivers such as the strength of Nationally Determined Commitments (NDCs) (Jun et al., 2016; Maltais & Nykvist, 2020). The institutional environment includes variables such as capital controls, regulatory quality, and the Rule of Law (Jun et al., 2016), while macroeconomic factors include GDP, openness to trade, the country's stock market capitalization, and many others (Sabuj et al., 2019). Green bond issuance remains overwhelmingly challenging in the energy sector (Ning et al., 2022), and ongoing geopolitical events could further complicate it. The Russia-Ukraine conflict that began in 2022 led to wild swings in oil and gas prices worldwide, following the COVID-19 pandemic. This could lead to a renewed focus on green bonds, and research shows that there might be a positive impact in the short run, and oil prices negatively affect the Green Bond Index in the medium and long term (Su et al., 2023), so they move inversely. While the recent banking collapses were an unexpected setback, and the market is cautious about a recession, once the debt market resumes business as usual, the green bond market should continue its growth unimpeded. Since traditional bonds do not elicit a positive market reaction, the positivity could be attributed to the bond's "Greenness" (Flammer, 2013). Green bonds are also more resilient to shocks and macroeconomic events (Contractor et al., 2023), so investors would treat them more favorably regarding economic uncertainties and high volatility in macroeconomic factors.

5. Future Research Implications of Green Bonds for Sustainable Clean Energy

Green bonds offer a promising avenue for promoting environmentally conscious initiatives in the clean energy and sustainability sectors. Highlighting the benefits of eco-friendly innovations and the potential for economic growth, green bonds also raise specific concerns, including the risk of greenwashing and the lack of standardized practices. To tackle these challenges, it is crucial to establish clear criteria, enhance accountability, and continuously refine regulations (Sabuj et al.,2019). Collaborative efforts among governments, industry, and research institutions are essential to seize emerging opportunities in clean energy transmission, foster innovation, and ensure a comprehensive response to the evolving landscape. Policy development, focusing on robust frameworks, stringent criteria, and global harmonization, is pivotal for unlocking and maximizing opportunities, boosting investor confidence, and facilitating the transition to a low-carbon economy (Ehlers & Packer, 2017).

The study conducts a thorough review of the literature on green bond issuance for clean energy and uses bibliometric clustering to identify four key policy implications (discussed below) that are considered important for addressing the challenges associated with green bond issuance for clean energy.

Building energy infrastructure and innovation: Policymaking for green bonds and similar green financial instruments is difficult to manage because economic decisions can spill over across instruments. Hammoudeh et al. (2020) suggested that, in addition to the strong predictive power of traditional bonds and CO2 emission prices, the causal effect of green bonds on clean energy innovation policies should be examined independently of them. Chang et al. (2023) and Saha et al. (2024) suggested that policymakers should focus on remittances and returns on investment to encourage private investment, as enhancing green tech growth is a crucial component of both short- and long-run growth recovery.

Table 6: Policy Cluster, Challenges, and Future Research Questions

Policy Clusters	Challenges	Future Research Questions (PRQ)
Building energy infrastructure and innovation	1. Scarcity of natural resources for building clean energy infrastructure. 2. Associated challenges with integrating renewable energy sources into existing infrastructure grids. 3. Lack of regulatory frameworks and a knowledge gap in strategic investment decisions. 4. Updated technology, skilled workforce, and overall supply chain obstacles. 5. The integration complexity of leveraging Industry 4.0 technologies into existing energy infrastructure and the undefined key factors in integrated strategies. 6. Underdeveloped research and development sectors and a lack of carbon capture and storage (CCS) infrastructure development.	PRQ1: How can inventive technologies, sustainable sourcing practices, and principles of a circular economy be leveraged? PRQ2: How can green bonds reduce the associated challenges of integration between renewable energy sources and existing infrastructure grids? PRQ3: What innovative technological solutions, regulatory frameworks, and investment strategies can be implemented? PRQ4: How do different approaches to integrating Industry 4.0 technologies into existing energy infrastructure impact the effectiveness of energy efficiency optimization efforts? PRQ5: What role can green bonds play in incentivizing research and development (R&D) efforts focused on advancing carbon capture? PRQ6: What storage (CCS) technologies ensure Eco-Friendly Infrastructure development?
Financial regulation, International climate accord, and governmental policy	7. An imbalance between profitability and default risk for banks engaging in green bond lending and improper management in promoting clean energy. 8. There is regulatory ambiguity, inadequate disclosure and transparency practices in the overall green bond markets, and a lack of regulatory measures. 9. Existing environmental finance mechanisms, such as the Clean Development Mechanism (CDM) and the Green Climate Fund (GCF), are limited in their ability to effectively address the clean energy transition and sustainable development goals. 10. Complexity of securitization structures and ensuring liquidity for green bond financing in energy transition projects. 11. The impact of Basel III regulations is that banks are more reluctant to finance energy transition projects that require long-term financing. 12. Inadequate Governmental intervention and non-compliance with global agreements.	PRQ7: How can we effectively manage the imbalance between profitability and default risk to promote green bonds in sustainable clean energy? PRQ8: How to mitigate uncertain events to ensure the continued growth and effectiveness of green bonds? PRQ9: How can regulatory ambiguity and inadequate disclosure and transparency practices within the green bonds market be resolved? PRQ10: How do variations in regulatory measurement techniques like renewable portfolio standards and feed-in tariffs across different jurisdictions influence the selection of renewable energy projects? PRQ11: What initiatives can be taken to increase the harmonization of environmental policy in different continents to finance long-term energy transition projects? PRQ12: How can we build better international strategies regarding government interventions, public-private partnerships, subsidies for transmission, following international accords, and financial incentives such as tax credits and grants?
Driving to a low-carbon and green economy	13. High economic cost of transition to a low-carbon economy and failure to provide a subsidy at the initial stage to substitute the fossil fuel economy with available renewable energy sources.	PRQ13: What factors need to be addressed to reduce high economic costs and realize long-term economic benefits? PRQ14: How can collaborative partnerships and knowledge-sharing initiatives broaden to encourage

	14. Unwilling to take various initiatives and incentives for transitioning traditional industries to low-carbon and green economy models.	traditional industries to adopt low-carbon and green economy models?	
	15. High reliance on fossil fuels for economic growth, especially in developing countries, and unwillingness to adopt renewable energy-based economies.	PRQ15: What type of incentive assists developing countries in moving from a fossil fuel-based economy to a renewable energy-based economy?	
	16. Insufficient Socio-Political attention for an effective green economy outlook in the long run	PRQ16: How do socio-political factors influence government policies, public perception, and investment decisions in green growth?	
	17. Lack of awareness about the benefits of carbon pricing mechanisms and failure to implement this to support a sustainable economy.	PRQ17: What potential benefits do carbon pricing mechanisms, such as carbon tax and cap-and-trade systems, offer in terms of reducing carbon emissions?	
Making green bonds investors-friendly	18. Lack of standardization in green bond policy, frameworks, and evaluation criteria.	PRQ18: How can the lack of standardization policy, frameworks, and evaluation criteria be addressed, and their impact on making green bonds more investor-friendly?	
	19. Asymmetric responses of investors to environmental concerns and green bond performance in specific market states.	PRQ19: How do the varying degrees of investor attention to environmental concerns and green bonds during different market states impact the performance of green assets?	
	20. Risk associated with effective hedging strategies of green bonds with renewable energy investments.	PRQ20: What hedging strategies can be developed to mitigate the risks associated with renewable energy investments through green bonds?	
	21. Scalability Issues to meet the funding requirements for large-scale clean energy projects.	PRQ21: What initiatives are needed to scale up green bond investments to meet the funding requirements for large-scale clean energy projects?	
	22. Market fragmentation and weak financial markets in developing or less developed countries.	PRQ22: How do market fragmentation and the weakness of the financial market impact the accessibility and effectiveness of green bond investments	
	23. The eligibility criteria of organizations to issue green bonds depend on their high green credentials, which may limit the pool of potential green bond issuers.	PRQ23: What alternative approaches or criteria could be considered to broaden the pool of potential green bond issuers?	

Financial regulation, international climate accord, and governmental policy: Tolliver et al. (2020) have demonstrated that policies positively and significantly impact renewable energy and that NDCs under the Paris Agreement affect green bond allocation. However, while making green bond-promoting policies, policymakers are advised to remain vigilant about the effect it could have on traditional markets, as Ren et al. (2023) caution that aggressive climate policies could affect both markets similarly, so similar weight needs to be afforded to both traditional and green energy markets in any proposed policy framework to regulate the flow of funds regarding green bond or any other financial instrument dealing with energy markets.

Driving toward a low-carbon, green economy: Zhao et al. (2022) cited Japan's Green Bond Grant as an example of policy adoption that has reduced greenhouse gas emissions, focusing on enterprises within the country and requiring debt restructuring to support the circular economy. They argued for more public awareness campaigns and policies that support private-public partnerships (PPPs), while calling for tighter regulations on green bond funds to ensure that commercial banks do not tap them to meet cash flow needs amid the easing of green bond borrowing. Hence, raising public awareness about building a low-carbon economy is an excellent fit for the policy framework to build PPP.

Making green bonds investor-friendly: Ferrer et al. (2021) warn policymakers about the volatility of the green bond market and that adding GBs to portfolios with mainly treasury and investment-grade assets should offer greater diversification benefits in the short term. This suggests that overzealous policies, such as including green bonds alongside traditional or risky energy assets, will not be beneficial in the short term. They suggested establishing a global framework to bridge the gap between the global green bond market and the currency market. Tiwari et al. (2022) found that green bonds received the most shocks from renewable energy markets as renewable energy and green bond prices moved together. Hence, any policy regarding economic recovery needs to be built with that in mind. Researchers have urged policymakers to carefully monitor public clean energy funding to prevent any adverse effects on green bonds.

The study identifies several challenges that must be addressed for green bonds to be used effectively to finance clean energy projects. To address these challenges, the study proposes research questions based on each policy implication, providing a framework for future research in this area. By doing so, the study aims to contribute to the development of effective policies for green bond issuance that can help to address the challenges facing the clean energy sector.

Furthermore, the study discusses the opportunities and risks associated with the green bond's future course of action to solve clean energy problems. This includes an analysis of the potential benefits green bonds can offer and the risks that must be overcome to ensure their success.

6. Conclusion, Implications, and Limitations

This study examines research trends in green bonds in the global context of clean energy using bibliometric analysis. Our bibliometric analysis shows that, although the Paris Accord occurred in 2015, the effect on research did not kick in until 2019. It is worth noting that China is prominent in the research of energy transition and green bonds. Ren et al. (2022) studied the green bond market in China and found that it has greater potential to reduce energy dependency and offer more options for carbon-emission projects. One of the three universities publishing the most articles, namely Central South University, is from China. The other two universities, Tokai University and Hasanuddin University, are from Japan and Indonesia, respectively. China's contribution to SCP and MCP is far greater than that of other countries, indicating that It is strongly committed to meeting its carbon-neutrality goals. It is also evident that China was producing articles only partially before 2021. China is a significant force in green bonds research on energy efficiency financing, with 41 articles and 732 citations, suggesting that it is very concerned about reducing its dependence on fossil fuels. Apart from top collaboration with China and Pakistan, we noticed strong author collaboration between the UK-Australia and India-Japan. Even though developed countries in Europe and North America are vocal about replacing fossil fuels with clean energy and are at the forefront of climate change concerns, their contribution to financing the energy transition through green bonds is not significant. Bhutta et al. (2022) highlight that green bonds are the most suitable instrument for financing environmentally friendly projects, especially in developing economies where governments may lack the financial means to implement them. However, we noticed collaborative efforts among developed and developing countries, including India, Sweden, the UK, and Ghana. It turns out that the Environmental Science and Pollution Journal is the most influential as it published 8 articles. It also appeared that Taghizadh-Hesary is the most influential author in this arena, having published 6 articles, followed by Li and Rasoulinezhad, each with 4 articles. Among the keywords in this field, Green Bond has occurred most frequently, followed by green finance, clean energy, and energy efficiency. From a practical perspective, a green bond is often treated as an equivalent to green financing. The factorial analysis and thematic map showed that green bonds, economic growth, energy efficiency investment, renewable energy, and carbon emission are highly researched topics. The findings from the thematic analysis have identified emerging fields such as clean energy, sustainable finance, and digital finance, which, if further analyzed, could yield

new insights into the green bonds literature in the context of green energy. Regarding co-cited network clusters, Zhang, Rasoulinez, Naeem, Reboredo, Taghizadeh-Hesary, and Mohsin are prominent researchers driving the research agenda on green bonds in energy transition. Based on network analysis results, the significant clusters revolve around green bonds, energy efficiency, green finance, clean energy, and sustainable development.

Regarding the effectiveness of green bonds for the transition to clean energy, we noticed a significant funding gap to move away from fossil fuels. With its current market size, green bonds must still be suited to tackle that issue. Despite green bond vulnerabilities such as a lack of standardization and data/credit ratings, the market remains optimistic that it can bounce back from its growth stumble amid the turbulent energy market. Furthermore, the confluence of technological advancements, collaborative governance, and innovative financial instruments provides the bedrock for unlocking the vast potential of green bonds in clean energy transmission. Despite the prospects, barriers to the widespread adoption of green bonds for energy transitions include financial institutions' reluctance to invest in small-scale projects, challenges in unorganized financial markets, regulatory ambiguities, and concerns about greenwashing, underscoring the need for clear criteria, transparency, and due diligence.

This study contributes to the current theoretical literature on green bonds as sustainable financing, particularly in the transition to clean energy. Limited research has been conducted, encompassing both quantitative and qualitative approaches, to examine the trends, current practices, and future research implications of the effectiveness of green bonds in facilitating the transition to renewable energy. This study also contributes to understanding how market expectations and investor sentiment should be aligned to foster broader acceptance of green bonds and reduce the vulnerabilities of the clean energy sector. Lastly, this study presents compelling points for policymakers, banks, and governments to discuss the opportunities to make green bonds a compelling differentiator, foster the long-term infrastructure for green clergy, and carefully mitigate stakeholders' threats to sustainable green financing and energy viability.

Countries worldwide are warming to the idea of using green bonds to meet the climate targets pledged under the Paris Agreement. The paper argues that the existing literature supports the claim that green bond-promoting policies lead to more funds flowing into such projects, so it is natural to see such policies being pushed. This study shows that green bond policies are at different stages worldwide; therefore, developing countries may not adopt policies enacted by developed countries simultaneously. Recognizing notable scholars, affiliated institutions, and publishers interested in the intersection of green bonds and clean energy can be beneficial for researchers and academics. This can help expand research in this area and ensure the outcomes of funded sustainability projects. We noticed that emerging bond markets are still growing; however, the urge to finance clean energy projects demands immediate financing action from market makers in sustainable projects. Moreover, practitioners can use bibliometric analysis results and future implications to derive actionable insights, track the viability of financing the energy transition, and assess long-term compatibility, rather than falling into the illusion of greenwashing or treating it as just a diversification tool. Regulators and policymakers can use the results of the research questions to develop a unique framework for strategic thinking and an actionable development plan for green bonds to achieve a positive impact on energy efficiency.

This study considers articles from the Scopus database and follows specific criteria, including language, time frame, and subject areas to be included; however, considering the Web of Science and a more objective methodology might yield more sophisticated results. Second, the study has treated green bonds as a form of green financing; however, from a practical perspective, they are equivalent to green financing. The theoretical differences might prevent the findings of this research from being applied to green financing considerations on clean energy.

Future research should include more dynamics of green bond financing and analyze the clean energy transition. Second, the research agenda should extend to economic and political issues, such as the Ukraine-Russia war, inflation, the Israel-Palestine conflict, and OPEC fossil fuel production, to examine the impact

of the energy transition. Third, future studies should distinguish between developed and developing countries, examine differences in economic viability, and focus on transition plans that reflect knowledge and policy to countries that need them most. Lastly, the gradual deployment of green bonds for clean energy depends on many enablers, such as green technology, green bond market structure, reporting, and standardization, so future researchers need to outline the effects of these enablers on clean energy's long-term sustainability.

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