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-RESEARCH ARTICLE-

A BIBLIOMETRIC STUDY OF CLIMATE FINANCE: MAPPING KNOWNS AND CHARTING THE UNKNOWNS

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─Abstract─

This study of climate finance is crucial for providing valuable insights and guidelines for informed decisions and strategic planning in promoting sustainability and addressing the challenges of climate change. This study utilizes bibliometric analysis to expand and enhance the existing body of research on climate finance. This study comprehensively overviews the latest advancements and emerging patterns in this field. This study acknowledges the remarkable progress achieved in recent years, primarily attributed to the Climate Agreement and the efforts of prominent nations, including China, the UK, and the US. The methodology of the current study involved conducting

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Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

a bibliometric analysis of climate finance literature spanning 2003 to 2023. Data for articles were retrieved from Web of Science, with data collection starting in October 2023. Bibliometric analysis was chosen as the best technique to examine the dataset because it can handle large amounts of bibliographic data without potential interpretation bias. By extensively analyzing the existing literature, this study identifies and explores seven dominant themes currently prevalent in climate finance research: Green Bonds, Green Innovation, Green Finance, Green Energy, Sustainable Finance, Green Banking, and Green Research. Additionally, this study offers insightful information about the significant authors, countries, journals, and papers that influence the field of climate finance. This information gives financial practitioners and policymakers a strong foundation for making well-informed decisions that pave the way for climate resilience and sustainability. Using this knowledge, we can help create a greener future for the community and its people.

Keywords: Climate Finance, Green Bonds, Green Finance, Sustainable Finance, and Bibliometric Analysis.

JEL Codes: G30, G38

INTRODUCTION

Climate finance is vital to global responses to climate crises. It encompasses all the financial resources, investments, and mechanisms aimed at mitigating the impacts of climate change and making it easier for people to adapt to its effects. Owing to the urgency of climate change, the critical role of finance in promoting sustainable and resilient development is now more universally recognized. Climate finance operates on many scales, from global funding agreements to small community initiatives. It supports various projects and activities, such as disaster risk reduction and climate-resilient infrastructure development of renewable energy projects. The objectives outlined in international agreements such as the Paris Agreement and the United Nations Sustainable Development Goals must be achieved to fully utilize this diverse landscape of climate finance (SDGs). Governments, financial institutions, the private sector, and civil society organizations are all involved in allocating financial resources to climate action. Transparency, accountability, and state-of-the-art financial instruments are required to mobilize significant investments to initiate the transition towards a low-carbon and climate-resilient economy.

Capital flows towards environmentally sustainable investments and incentivizing eco-friendly practices, which can be encouraged by climate finance. This study examined all financial products related to budgetary matters, including green bonds, sustainable investment funds, carbon pricing mechanisms, and innovative financing options that integrate environmental considerations. Climate finance is a crucial tool for achieving development objectives. However, several obstacles and impediments restrict their

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

broad application and relevance. In particular, developing countries face difficulties meeting their environmental objectives owing to their scant financial resources and investment capital for green initiatives. One of the most significant challenges in funding environmental sustainability projects is the scarcity of adequate funds and their allocation to inappropriate endeavours, ultimately impeding the eco-friendliness of the economy.

However, various challenges and obstacles limit their extensive use and applicability. Developing countries often face a scarcity of the financial resources and investment capital necessary to back green initiatives, which can impede the realization of desired goals. A considerable barrier to financing environmental sustainability projects is the inefficient distribution of funds to unsuitable endeavours, which hinders the nation's environmentally friendly economic activities. Robust and efficient regulatory and policy frameworks that encourage and facilitate environmentally sustainable financial practice are crucial. Financial institutions and investors may be reluctant to invest in green initiatives because of the perceived risks and uncertainties without such guidelines, standards, and accountability measures.

Over the past few decades, new financial instruments such as green or climate bonds have emerged and gained popularity after the European Investment Bank (EIB) was founded in 2007. According to Climate Bonds Market Intelligence, as of 2021, over half a trillion dollars ($517.4 billion) worth of green bond issuance has occurred. Despite the significant expansion of green bonds, questions remain unanswered about what qualifies as a 'green' bond and whether they genuinely offer environmental benefits. Furthermore, implementing an emissions trading system (ETS) has resulted in the emergence of innovative financial products within the broader carbon finance sector. Technological advancements have opened new opportunities to provide financial resources to support climate action. These climate-driven financial innovations have introduced new features and risk elements, which have received significant academic attention. Furthermore, the development of climate finance has been linked to changes in financial services, creating a need for individuals with interdisciplinary backgrounds and expertise. A considerable amount of recent research has been conducted on climate finance. Researchers have explored various avenues of research in this area, but their findings need to be summarized to understand the major themes, development, and future directions of this field.

This study aimed to summarize research in a particular field using bibliometric analysis. Its objectives are twofold. First, it provides a quantitative assessment of the performance of different research constituents. Second, it qualitatively assessed themes, their development, and future directions. Given the significant volume of research produced by researchers, bibliometric analysis is considered an appropriate method for this type of analysis.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

A bibliometric analysis is a systematic literature review Mukherjee et al. (2022) that uses statistical and quantitative tools for bibliographic data (Broadus, 1987; Pritchard, 1969). This method can help researchers to obtain a comprehensive and up-to-date overview of a particular field. In the case of climate finance, this approach can help identify leading players and arenas in the field and show how they have evolved. The importance of climate finance has recently increased owing to commitments by developed countries to support developing nations for climate-related projects, financially challenging flows to areas where it is most needed.

The purpose of this study is to present a thorough overview of the climate finance landscape. It analyses the field's mechanisms, players, and challenges in identifying well-known realities and uncharted territories. In doing so, we aspire to contribute to the ongoing dialogue on climate finance by providing insights that can help shape financial strategies, influence policy decisions, and ultimately accelerate our group efforts to address the climate crisis. Climate finance is a critical element in the management of global climate crises. This bibliometric study aimed to unravel the complex web of climate finance research. We contribute to this research in two ways. First, we provide an overview of this field using a bibliometric analysis. Second, we identify seven themes that seem to capture most of the research outputs, discuss these themes, identify overlaps and gaps, and suggest areas that require further research. Our findings and suggestions are useful for future research.

BOTTOM OF FORM

The following are some potential research questions that this study addresses:

RQ1: How has the distribution of climate finance research evolved regarding the total number of publications and research areas between 2003 and 2023?
RQ2: What are the notable contributions and innovative ideas introduced by the authors with the highest publication output, leading countries, prestigious journals, and influential publications in climate finance research?
RQ3: How have co-citation studies progressed to form significant clusters with distinct research focuses?
RQ4: Which areas have experienced the highest levels of activity, what are the recent trends in research, and what are the emerging themes in climate finance research?

These research questions align with the goals of performing a bibliometric study of the literature on climate finance, which aims to reveal patterns and identify areas that require further research. Researchers can refine these questions based on a particular dataset and study goals. The remainder of this paper is organized as follows. The research methodology is outlined in the next section. The performance and thematic analyses of the corpus are presented in the following two sections. The last two sections of the study consist of the results and discussion, followed by a conclusion.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

DATA SEARCH

The authors searched the literature for various synonyms related to climate finance as well as the varying kinds of financing initiatives that fall under the umbrella of climate finance to create the keyword string "*Green Bond**" OR "*Green Finance*" OR "*Climate Bond**" OR "*Climate finance*" OR "*Sustainable Finance*" OR "*Carbon Finance*." The data for these articles were retrieved from the Web of Science, with data collection beginning in October 2023 and spanning 2003–2023. The filters used only covered relevant results. This meant restricting the content types to articles and reviews, excluding books, conference papers, and book chapters. This was performed to ensure the quality of the papers. After controlling for paper quality, we retained the papers in economics, finance, econometrics, management, accounting, business, and financial economics. This was performed to ensure that our dataset contained only the articles and reviews pertinent to the topic. Through this process, we obtained a dataset of 1,488 articles and reviews and used them in subsequent analyses.

METHOD OF ANALYSIS

Given the corpus size, bibliometric analysis is the best technique for examining the datasets. This is primarily because bibliometric analysis can handle large amounts of bibliographic data without potential interpretation bias (Donthu et al., 2021).

Various tests and analyses were conducted to extract valuable insights from the 1,488 articles and review datasets. Researchers have systematically examined a large dataset of articles and reviews in economics, finance, econometrics, management, accounting, business, and financial economics.

These techniques have investigated the effectiveness and influence of various study constituents, including authors, countries, journals, and publications. The researchers also employed bibliographic coupling to analyse the themes found in the corpus, creating thematic clusters of documents based on cited references as a similarity index. Previous studies that have used a similar methodology include (Kessler, 1963; Newman, 2004; Van Eck & Waltman, 2010; Wallin, 2005; Weinberg, 1974). These studies employed bibliographic coupling, thematic analysis, and bibliometric mapping techniques to analyse research sources, identify thematic clusters, and visualize data in the field of climate finance. Trend topic maps were used to augment the data, and keyword analysis was employed to examine thematic progression in the field. Researchers have also used software programs, such as NVivo 14 and VosViewer Van Eck and Waltman (2010), to perform analyses and visualizations. Through these analyses and tests, researchers were able to identify major themes, trends, and future directions in economics, finance, and related disciplines.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Researchers have achieved their study objectives through various means. To achieve our first objective, we examined the effectiveness and influence of several study constituents. Therefore, we summarize and explore a range of authors, countries, journals, and publications, paying particular attention to their productivity and measuring the number of citations they have received over time. Scholars seeking to identify the most prominent and widely used research sources in this field will find this helpful. To achieve our second research objective, we used bibliographic coupling to analyse the themes found in the corpus (Weinberg, 1974). This type of research creates thematic clusters of documents by employing cited references as a similarity index (Weinberg, 1974). More standard literature references indicate more similarities and vice versa (Wallin, 2005). An algorithm created by Newman (2004) was used to divide the articles into thematic clusters based on the similarity index of the number of standard literature references. The resulting thematic clusters were reviewed to identify the major themes in the corpus. Trend topic maps were used to augment the data. Furthermore, the field's thematic progression was examined through keyword analysis, and the future direction of each theme was identified.

Performance analysis

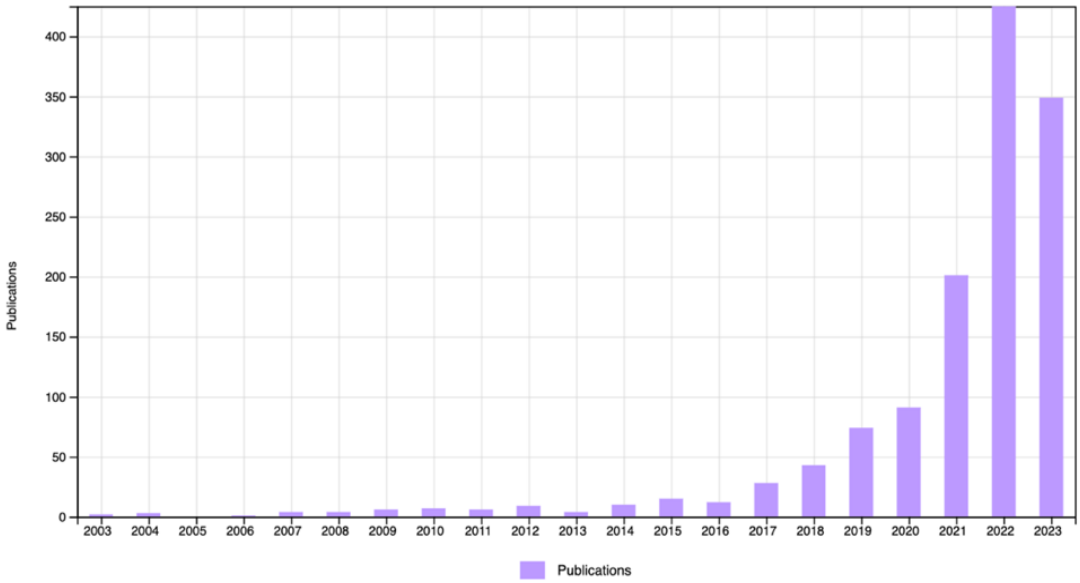

Figure 1: Publication of yearly climate finance trends.

The central outcome of our study is the interpretation of the findings, through which we extracted valuable insights from highly productive authors, countries, journals, themes, and clusters. Alongside identifying research gaps and potential future directions in the domain of climate finance, we also examine the implications of our findings. Utilizing this comprehensive bibliometric analysis, we can effectively chart the known aspects

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

and identify unknown areas in climate finance research. This provides significant data for academics, decision-makers, and other stakeholders interested in climate finance and sustainable development. As depicted in Figure 1, the 2010s witnessed a significant surge in the number of publications that focused on climate finance. Notably, there was substantial growth in the number of publications in 2012. However, most publications were published in 2016, with a notable exponential increase.

This pattern emerged in response to increasing interest in the topic following the signing of the Paris Agreement in 2017 and the adoption of the UN General Assembly's Sustainable Development Goals in 2015.

The authors and countries that have contributed significantly to climate finance are listed in Table 1. Farhad Taghi-Zadeh-Hesary has emerged as the most productive author, with an impressive 20 publications in this field. Muhammad Abubakr Naeem follows closely with a commendable count of 12 publications. Among the nations, China is recognized as the frontrunner, showcasing exceptional productivity with a remarkable 742 published works. The United States, England, and Pakistan also demonstrate noteworthy contributions, with publication counts of 144, 127, and 98, respectively.

Table 1: Prolific Authors and Countries

Most Prolific Authors	TP	TC	Most Prolific Countries	TP	TC
Taghizadeh-Hesary, Farhad	20	1489	Peoples R China	742	13726
Naeem, Muhammad Abubakr	12	628	USA	144	3508
Tiwari, Aviral Kumar	9	362	England	127	3230
Ren, Xiaohang	9	137	Pakistan	98	2471
Sadiq, Muhammad	8	412	Australia	76	2162
Umar, Muhammad	8	92	India	71	1557
Mohsin, Muhammad	7	663	France	70	2109
Abakah, Emmanuel Joel Aikins	7	317	Germany	66	1477
Rasoulinezhad, Ehsan	7	275	Italy	56	1374
Iqbal, Wasim	7	178	Malaysia	53	1925
Lee, Chien-Chiang	6	643	Vietnam	49	1692
Managi, Shunsuke	6	558	Japan	45	2401
Lee, Chi-Chuan	5	514	Spain	42	1085
Sharif, Arshian	5	418	Netherlands	33	1118
Yoshino, Naoyuki	5	379	Sweden	32	748
Zhou, Xiaoguang	5	282	Russia	22	485
Razzaq, Asif	5	234	Saudi Arabia	20	378
Karim, Sitara	5	166	Ireland	17	645
Adekoya, Oluwasegun B.	5	93	United Arab Emirates	15	562
Mensi, Walid	5	75	Brazil	12	455

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Table 2 presents a comprehensive overview of leading climate finance journals. Topping the list is the esteemed journal Sustainability, known for its significant contributions, with 213 published articles. Trailing behind, but still noteworthy, are Environmental Science and Pollution Research and the Journal of Cleaner Production, having published 154 and 64 articles, respectively.

Table 2: Prominent Journals

Most Prolific Journals	TP	Most Impactful Journals	TC
Sustainability	213	Journal of Cleaner Production	2462
Environmental science and pollution Research	154	Sustainability	2143
Journal of Cleaner Production	64	Environmental science and pollution	2069
Energy Economics	55	Energy Economics	1849
Frontiers in Environmental Science	54	Finance Research Letters	1819
Renewable Energy	46	Energy Policy	1777
Finance Research Letters	42	Technological Forecasting and Society	1043
Energy Policy	29	Renewable Energy	675
International Journal of Environmental Research and Public Health	29	Journal of Sustainable Finance & Investment	658
Journal of Sustainable Finance & Investment	27	Journal of Environmental Management	592
Technological Forecasting and Social Change	24	International Review of Financial Analysis	375
International Review of Financial Analysis	20	Business Strategy and the Environment	355
Journal of Environmental Management	19	Economic Analysis and Policy	351
Economic Analysis and Policy	16	Global Finance Journal	335
Business Strategy and the Environment	16	International Journal of Environmental Research and Public Health	310
Journal of Risk and Financial Management	14	Frontiers in Environmental Science	289
Global Finance Journal	10	Economic Modelling	258
Borsa Istanbul Review	7	Borsa Istanbul Review	248
Economic Modelling	6	Journal of Risk and Financial Management	239
North American Journal of Economics and Finance	6	North American Journal of Economics and Finance	209

Surprisingly, although sustainability may have published the most articles, it fell slightly behind in the prestigious Journal of Cleaner Production, which commands the highest number of citations, an impressive 2,462. The following are Sustainability and Environmental Science and Pollution, accumulating substantial citation counts of 2,143 and 2,069, respectively. These figures highlight the influential nature of these journals in climate finance.

Table 3 presents a compilation of publications with the highest number of citations in climate finance. Publications with the highest number of citations Zerbib (2019) were

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

referenced 500 times.

Table 3: Leading Articles

Authors	Title	Year	Journal	TC	C/Y
(Zerbib, 2019)	The effect of pro-environmental preferences on bond prices: evidence from green bonds	2019	Journal of Banking & Finance	500	231.0
(Taghizadeh-Hesary & Yoshino, 2019)	The way to induce private participation in green finance and investment.	2019	Finance Research Letters	368	124.75
(Reboredo, 2018)	Green bond and financial markets: co-movement, diversification, and price spillover effects.	2018	Energy Economics	334	97.20
(Hachenberg & Schiereck, 2018)	Are green bonds priced differently from conventional bonds?	2018	Journal of Asset Management	255	85.60
(Gianfrate & Peri, 2019)	The green advantage: exploring the convenience of issuing green bonds	2019	Journal of Cleaner Production	214	123.25
(Bachelet et al., 2019)	The green bonds premium puzzle: the role of issuer characteristics and third-party verification	2019	Sustainability	186	102.5
(Mohsin et al., 2021)	Developing low carbon finance index: evidence from developed and developing economies.	2021	Finance Research Letters	181	6.0
(Nguyen et al., 2021)	Time-frequency co-movement among green bonds, stocks, commodities, clean energy, and conventional bonds	2021	Finance Research Letters	164	115.50
(Febi et al., 2018)	The impact of liquidity risk on the yield spread of green bonds	2018	Finance Research Letters	138	53.80
(Tolliver et al., 2020a)	Drivers of green bond market growth: the importance of nationally determined contributions to the Paris agreement and implications for sustainability	2020	Journal of Cleaner Production	126	80.0
(Tiwari et al., 2022)	Dynamic spillover effects among green bond, renewable energy stocks, and carbon markets during COVID-19 pandemic: Implications for hedging and investments strategies.	2022	Global Finance Journal	121	145
(Hammoudeh et al., 2020)	Relationship between green bonds and financial and environmental variables: a novel time-varying causality	2020	Energy Economics	118	52.33
(Liu et al., 2021)	Dependence and risk spillovers between green bonds and clean energy markets	2021	Journal of Cleaner Production	116	80.0
(Naeem et al., 2021)	Comparative Efficiency of green and conventional bonds Pre—and during Covid-19: an asymmetric multifractal detrended Fluctuation Analysis	2021a	Energy Policy	99	76
(Tu et al., 2020)	Investigating solutions for the development of a green bond market: Evidence from analytic hierarchy process.	2020a	Finance Research Letters	68	29.0

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

This study uses green bonds as an indicator to evaluate the influence of non-financial elements, particularly pro-environmental inclinations, on prices within the bond market. Following this study Taghizadeh-Hesary and Yoshino (2019), 368 citations were accumulated, while (Reboredo, 2018) secured 334 citations. It is worth noting that both articles delve into subjects closely associated with green finance and bonds.

Analysis of themes

We employ a bibliographic coupling method to examine the primary themes of climate finance. Using an analytical tool, we identified seven major theme clusters. Initially, our analysis revealed nine clusters; however, we ultimately recognized only seven as significant, consisting of ten or more papers. These themes, comprising 94% of the entire corpus (1400 out of 1488 articles), provide a dependable representation of the key topics explored by the authors. In examining these significant clusters, we observe that clusters 1–7 encompass discussions on Green Bonds, Green Innovation, Green Finance, Green Energy, Sustainable Finance, Green Banking, and Green Research, respectively. A detailed analysis of these themes is provided in the next Section. Moving forward, we delve into the progressive development of the field through keyword co-occurrence analysis, and the last Section highlights potential future directions for each theme.

The main topic addressed by the authors was the use of green bonds as financial instruments. Flammer (2021) Corporate green bonds allocate their proceeds to finance environmentally and climate-friendly initiatives like renewable energy, sustainable buildings, and resource conservation. The prevalence of corporate green bonds is the highest in Europe, the US, and China. These bonds serve as a mechanism to promote decision-making that considers positive environmental and societal impacts. They contribute to sustainable development and economic growth (Tiwari et al., 2023). Companies can enhance their reputation as environmental leaders by issuing green bonds (Flammer, 2021). According to Tang and Zhang (2020) institutional ownership tends to increase when companies issue green bonds, especially with domestic institutions.

Furthermore, stock liquidity improves upon issuing green bonds that benefit the shareholders. The authors' emphasis on central banks is apparent from the frequency of the term "central banks." This highlights their focus on the risks associated with climate change, which can significantly impact the core responsibilities of central banks, mainly financial and monetary stability. Table 4 summarizes Cluster 1.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Major thematic clusters

Cluster #1: Green Bonds Market

Table 4: Cluster #1: Green Bonds Market

Author	Title	Year	Journal	TC
(Flammer, 2021)	Corporate green bonds.	2021	Journal of Financial Economics	272
(Dikau & Volz, 2021)	Central bank mandates, sustainability objectives, and the promotion of green finance.	2021	Ecological Economics	100
(Fan et al., 2021)	Greening through finance?	2021	Journal of Development Economics	81
(MacAskill et al., 2021)	Is there a green premium in the green bond market? Systematic literature review revealing premium determinants.	2021	Journal of Cleaner Production	78
(Maltais & Nykvist, 2020)	Understanding the role of green bonds in advancing sustainability.	2021	Journal of Sustainable Finance & Investment	77
Major Themes	Climate change, network for greening the financial system, financial stability, environmental risk, Corporate Sustainability, Climate change			

Cluster #2: Green Innovation

Wu and Wang (2023) provide an overview of how the availability of green credit and the level of financialization positively impact technological innovation, particularly in economically advanced regions such as China. Han and Li (2023) aimed to assist the government in developing appropriate policies to enhance the financial system and establish innovative mechanisms. To serve the better interests of financial market participants, better policies seek to reduce government intervention and improve the efficiency of financial resource allocation. According to Irfan et al. (2022), green finance will play a significant role in green innovation. The influence of green financing on innovation is observed through its impact on economic growth, R&D, and industrial structure. Cluster 2 focuses on Geographic Information Systems (GIS), environmental protection, and technological innovation. The goals of this cluster were to address carbon emissions, foster a green economy, and support environmentally friendly and sustainable development. It emphasizes the pivotal role of GIS and technology in promoting environmental initiatives and advancing towards a cleaner and greener future. A summary of these clusters is presented in Table 5.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Table 5: Cluster #2: Green Innovation

Author	Title	Year	Journal	TC
(Lee & Lee, 2022)	How does green finance affect green total factor productivity? Evidence from China.	2022	Energy Economics	311
(Irfan et al., 2022)	Influence mechanism between green finance and green innovation: Exploring regional policy intervention effects in China	2022	Technological Forecasting and Social Change	161
(Feng et al., 2022)	Environmental decentralization, digital finance, and green technology innovation.	2022	Structural Change and Economic Dynamics	131
(Zhang et al., 2023)	Can green finance promote urban green development? Evidence from green finance reform and innovation pilot zone in China.	2022	Environmental Science and Pollution Research	26
(Gao et al., 2023)	The impact of green finance on industrial reasonability in China: Empirical research based on the spatial panel Durbin model.	2023	Environmental Science and Pollution Research	25
Major Themes	Technological innovation, environmental protection, emission reduction, green economy, green development.			

Cluster #3: Green Finance

The third thematic cluster revolves around green financing. Within this context, Bhatnagar and Sharma (2022) suggested a green finance model to secure funds for environmental development. Utilizing e-allocation can advance both human development and ecological well-being while ensuring the conservation of natural resources. Green financing has garnered significant attention as an area with immense potential for funding renewable energy sources and addressing climate-change issues.

Gholipour et al. (2022) and Y. Wang et al. (2021) used data from various Chinese provinces from 2007 to 2017 to illustrate the green credit policy's substantial impact on economic activity and pollution reduction. The researchers employed Porter's effect theory, which suggests that green financing positively influences environmental quality. They explored key concepts using keywords such as renewable energy, environmental development, green economy, green climate fund, greenhouse gas, sustainable development goals, and environmental sustainability and quality. A concise summary of the identified clusters is presented in Table 6.

Cluster #4: Green Energy

Cluster 4 focuses on the concept of green energy. It explores renewable and sustainable energy sources such as geothermal, hydroelectric, solar, and wind. One of the primary motivations behind this study is the urgent need to reduce greenhouse gas (GHG) emissions to combat the detrimental effects of climate change. Green energy is an environment-friendly and sustainable alternative to traditional fossil fuels. Liu et al.

(2021) highlight the significant interdependence and risk spillover observed between the green bond market and sectoral renewable energy markets, aligning with the previous evidence linking green bonds and renewable energy markets. Notably, the impact of green bonds on the carbon market surpasses that of renewable energy stocks. This indicates the growing prominence of green-bond markets and increasing momentum behind renewable energy development, as highlighted by (Tolliver et al., 2020b)

Table 6: Cluster #3: Green Finance

Author	Title	Year	Journal	TC
(Taghizadeh-Hesary et al., 2021)	Analysing the characteristics of green bond markets to facilitate green finance in the post-COVID-19 world	202	Sustainability	57
(Lee et al., 2022)	The contribution of climate finance toward environmental sustainability: New global evidence	2022	Energy Economics	29
(Bhatnagar & Sharma, 2022)	Evolution of green finance and its enablers: A bibliometric analysis.	2022	Renewable & Sustainable Energy Reviews	26
(Gholipour, Arjomandi, & Yam, 2022)	Green property finance and CO2 emissions in the building industry.	2022	Finance Journal	23
(Quynh et al., 2022)	The role of climate finance in achieving COP26 goals: Evidence from N-11 countries.	2022	Cuadernos De Economia-Spain	23
Major Themes	Artificial intelligence, environmental development, renewable energy, Green Economy, Green Climate fund, Greenhouse gas, Sustainable development, environmental quality			

Tiwari et al. (2023) have observed that the expansion of green bonds (GB+) has a substantial positive impact on investments in renewable energy and concurrently reduces pollution levels. Conversely, the contraction of green bonds (GB+) leads to a significant decline in investment in renewable energy and a subsequent increase in pollution levels. Madaleno et al. (2022) This indicates that adopting such policies burdens firms with heavy pollution. Hence, policymakers and environmental investors can derive significant advantages from this study. The dominant themes encompassed in this cluster were government relief, clean energy, green technology, climate change, environmental responsibility, clean energy, and green investors. A comprehensive summary of Cluster 4 is presented in Table 7.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Table 7: Cluster #4: Green Energy

Author	Title	Year	Journal	TC
(Tiwari et al., 2022)	Dynamic spill over effects among green bond, renewable energy stocks, and carbon markets during COVID-19 pandemic: Implications for hedging and investments strategies.	2022	Global Finance Journal	99
(Madaleno et al., 2022)	A step forward on sustainability: The nexus of environmental responsibility, green technology, clean energy and green finance.	2022	Energy Economics	82
(Tan et al., 2021)	How COVID-19 induced panic on stock price and green finance markets: Global economic recovery nexus from volatility dynamics.	2022	Environmental Science and Pollution Research	71
(Naeem et al., 2023)	Religion vs. ethics: Hedge and safe haven properties of Sukuk and green bonds for stock markets pre- and during COVID-19.	2023	International Journal of Islamic and Middle Eastern Finance and Management	59
(Su et al., 2023)	Can the green bond market enter a new era under the fluctuation of oil prices?	2023	Economic Research-Ekonomska Istrazivanja	24
Major Themes	Government relief, clean energy, green technology, climate change, environmental responsibility, ethical investors, green investors			

Cluster #5: Sustainable Finance

Promoting environmentally and socially conscious investments in sustainable finance is crucial for aligning financial operations with a society's long-term ecological and social well-being. However, it is important to acknowledge the negative aspects of sustainable financing. Recent studies by Chen et al. (2020) have shed light on the factors that can undermine sustainable projects in developing nations, with a lack of funding being identified as a major cause of project failure. This finding is further supported by the research of Havemann, Negra, and Werneck (2020), who emphasized the necessity of financial support for developing the green agricultural product supply chain (GAPSC) and proposed the adoption of various financing modalities for this purpose. Notably, the analysis of Cluster 5 revealed significant themes, such as the agricultural industry, sustainable finance, greenwashing, socially responsible investing, and greenhouse gases. For a concise overview of the key findings in Cluster 5, see Table 8.

Table 8: Cluster #5: Sustainable Finance

Author	Title	Year	Journal	TC
(Tolliver et al., 2021)	Green innovation and finance in Asia.	2021	Asian Economic Policy	83
(Tu et al., 2021)	Using green finance to counteract the adverse effects of the COVID-19 pandemic on renewable energy investment-the case of offshore wind power in China	2021	Energy Policy	73
(Yu & Rehman Khan, 2022)	Evolutionary game analysis of green agricultural product supply chain financing system: COVID-19 pandemic	2022	International Journal of Logistics-Research and Applications	52
(Migliorelli, 2021)	What do we mean by sustainable finance? Assessing existing frameworks and policy risks.	2021	Sustainability	33
(Ziolo et al., 2021)	The role of sustainable finance in achieving sustainable development goals: Does it work?	2021	Technological and Economic Development of the Economy	30
Major Themes	Agricultural industry, sustainable finance, greenwashing, socially responsible investing, greenhouse gases.			

Cluster #6: Green Banking

Green banking is a revolutionary financial sector approach focusing on supporting projects and practices that benefit the environment. This involves banks and financial institutions investing in renewable energy, eco-friendly technologies, and projects that work to reduce carbon emissions. By doing so, green banking aims to positively impact the environment while promoting sustainable development and the responsible management of resources. Duchêne (2020) and Jeffrey et al. (2019) emphasize the importance of initiating green projects through various financial tools and policies such as green banks, green bonds, carbon market tools, and other innovative instruments. Additionally, they highlight the significance of fiscal policies, green central banks, fintech, community-based green funds, and financing expansion for investments that provide environmental benefits. These "green finance" efforts are necessary to achieve sustainable development goals.

According to Khan et al. (2022), the concept of green finance has garnered considerable attention in the recent literature owing to a heightened global focus on mitigating climate change. Previous studies have shown that green finance has the potential to improve environmental quality by implementing environmental funding laws and reducing carbon dioxide emissions (CO2) (Brandi et al., 2020; Li et al., 2019; Nouira et al., 2016). A summary of Cluster 6 is presented in Table 9.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Table 9: Cluster #6: Green Banking

Author	Title	Year	Journal	TC
(Khan et al., 2022)	The impact of carbon pricing, climate financing, and financial literacy on COVID-19 cases: Go-for-green healthcare policies	2022	Environmental Science and Pollution Research	72
(Wang et al., 2022)	Does green finance inspire sustainable development? evidence from a global perspective	2022d	Economic Analysis and Policy	40
(Sharma et al., 2022)	Revisiting conventional and green finance spill-over in post-COVID world: Evidence from robust econometric models	2022	Global Finance Journal	27
(Zhang et al., 2022)	Do green banking activities improve the banks' environmental performance? The mediating effect of green financing.	2022e	Sustainability	27
(Agyekum et al., 2022)	Obstacles to green building project financing: An empirical study in Ghana.	2022	Journal of Construction Management	2
Major Themes	Global Environment Facility, Ecological Footprints, Sustainable Growth, Green Climate funds, Greenhouse Gas, World Green Building Council, sustainable development			

Cluster #7: Green Research

Green research has become a critically important area of academic inquiry, focusing on advancing sustainable technologies and practices to mitigate environmental harm and foster ecological stability. This field encompasses a range of disciplines, including renewable energy, sustainable agriculture, environmental conservation, and green chemistry. Researchers in this domain have sought to develop ground-breaking strategies to reduce their ecological impact, conserve natural resources, and enhance biodiversity. The aim was to create solutions that advance sustainability and balance mankind’s needs and the planet's health. The significance of green research has grown in light of the profound challenges posed by climate change and environmental degradation. This drives the development of innovative solutions that strive to instil a greater sense of environmental consciousness and ensure the long-term viability of the world. A summary of Cluster 7 is presented in Table 10.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Table 10: Cluster #7: Green Research

Author	Title	Year	Journal	TC
(An et al., 2021)	Green credit financing versus trade credit financing in a supply chain with carbon emission limits	2021	Journal of Operational Research	161
(M. Wang et al., 2021)	Discovering research trends and opportunities of green finance and energy policy: A data-driven scient metric analysis	2021a	Energy Policy	61
(Soni et al., 2022)	A decision-making framework for industry 4.0 technology implementation: The case of FinTech and sustainable supply chain finance for SMEs	2022	Technological Forecasting and Social Change	39
(C. Wang et al., 2021)	Order financing for promoting green transition	2021e	Journal of Cleaner Production	35
(Chen et al., 2020)	Holding risky financial assets and subjective well-being: Empirical evidence from China	2021	The North American Journal of Economics and Finance	24
Major Themes	Green investment, carbon reduction commitment, green innovation, digital transformation, value creation, climate change, clean technology, and green transition Topics such as circular economy solutions, climate-resilient infrastructure, biodiversity finance, sustainable supply chains, and green technological advancements are proposed for future research.			

Keyword Analysis

Examining thematic progression in a particular field using keyword analysis is an appropriate and valid research approach. This method involves an in-depth analysis of how keywords are utilized and evolved in scholarly literature, allowing for the identification of shifts, trends, and advancements within the field. Valuable insights can be obtained by tracing the trajectories and evolution of the keywords over time. Comerio and Storz (2019) focused on author keywords as indicators of the themes present in research articles. They identified 4,929 keywords in 1,488 publications and explicitly investigated the top keywords used in climate finance research from 2003 to 2023. Among these keywords, "Green Finance" emerged as the most frequently used, appearing 376 times. This indicates that the concept of green finance has been widely discussed in literature. Additionally, the keywords "green bonds" (193 occurrences), "renewable energy" (122 occurrences), and "CO2 emissions" (110 occurrences) were frequently used.

A co-occurrence analysis was conducted using keywords that appeared ten times in the studies to further examine the relationship between keywords. This led to the identification of 425 keywords, of which the top 100 were selected and grouped into five clusters. The overlay visualization map of the keyword co-occurrence analysis reveals that these clusters represent common subject linkages within research projects.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

The map depicted in Figure 2 shows the interconnectedness of the clusters, with close circles indicating that researchers within related clusters are likely to be cited in similar situations. Through the analysis of keyword co-occurrence, the map provided a visual representation of the prevailing research topics of the year. Current trends in climate finance research emphasize green finance, green innovation, sustainable finance, digital finance, and technological innovation.

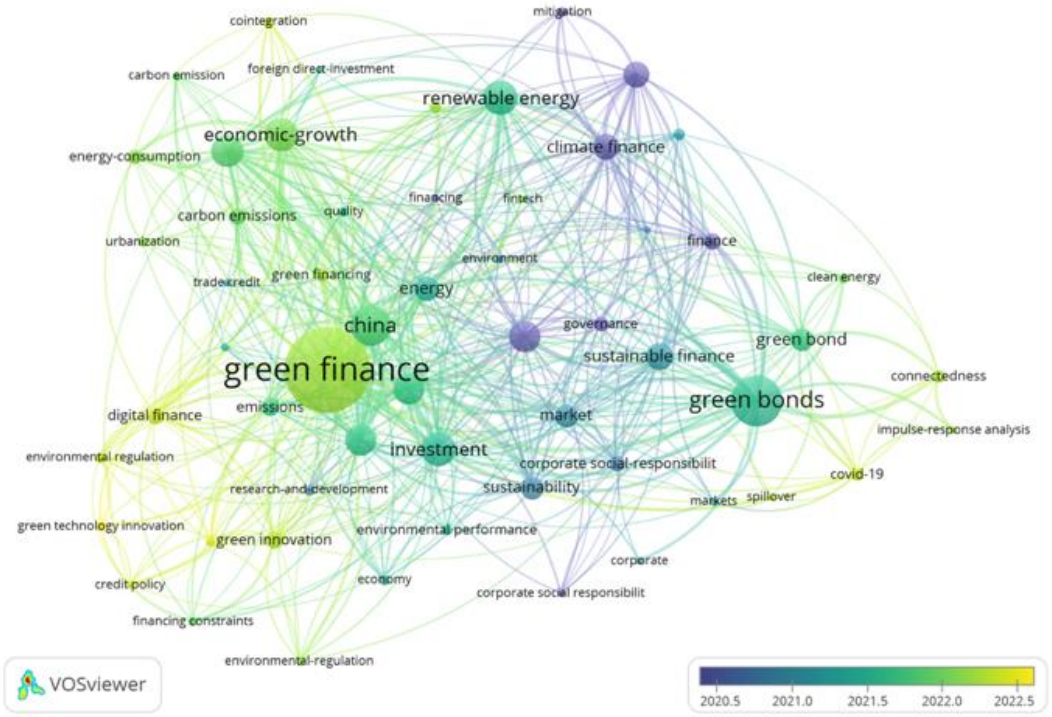

Figure 2. Keywords co-occurrence overlay visualization map according to year

FUTURE RESEARCH DIRECTIONS

The following sections highlight the future research directions and the potential for further exploration of each significant research cluster.

Future Directions for Cluster #1

The first cluster examined the correlation between green bonds and financial markets. The cluster aims to advance the growth of sustainable financing. It is imperative to raise investor awareness, foster innovation in green financial instruments, and enhance transparency and standardization in reporting practices. Additionally, it is crucial to establish global collaboration and develop regulatory frameworks that facilitate green

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

investments. To establish a robust green finance ecosystem, research should also explore the long-term effects of green bonds on sustainability and the environment while ensuring the involvement of diverse stakeholders. Therefore, we propose the following proposition.

Proposition 1a: What is the potential impact of a global financial market embracing sustainable credit schemes on environmental performance?

Proposition 1b: What are central banks' obligations regarding supporting green activities, including financing eco-friendly projects, incorporating climate-related risks into fundamental policy frameworks, and promoting sustainable growth?

Future Directions for Cluster #2

The promotion of sustainable solutions to environmental challenges relies heavily on interdisciplinary collaboration. Policymakers play a crucial role in this process by offering funding opportunities and regulatory support to incentivize green innovation. Additionally, cultivating sustainable business practices and fostering public-private partnerships can rapidly track the transition to a more resilient and environmentally aware global economy. Based on these considerations, we propose the following proposition.

Proposition 2a: To address environmental degradation and achieve sustainable development, should nations embrace various energy-saving techniques, reduce emissions, and implement green finance initiatives?

Future Directions for Cluster #3

The primary focus of this cluster study was to examine the impact of sustainability policies on businesses and individual investors. However, it is worth noting that some investors invest in green bonds and climate-friendly businesses to be more socially and environmentally responsible. The key concerns revolve around the effectiveness of these investments and whether investors are primarily motivated by signalling a positive message to society. The researchers did not delve into these aspects, focusing primarily on individual investments rather than the underlying intentions. To address this gap, further exploration is needed to determine the extent to which investors and firms are committed to climate financing and the extent to which this commitment relies on reducing investments in non-sustainable ventures. In light of these considerations, the following propositions are proposed:

Proposition 3a: Should regulations consider the role of climate change in global efforts to achieve carbon neutrality targets? Should they ensure that all policy frameworks

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

facilitate the adoption of climate finance, as it is crucial to address climate change and enhance environmental quality?

Proposition 3b: Should the significance of climate change in global carbon neutrality endeavours be acknowledged? Is it essential for policy frameworks to promote climate finance to combat climate change and to improve environmental quality?

Future directions for Cluster #4

Cluster 4 should prioritize energy in its future endeavors and reorient its attention toward advancing renewable technology research, including solar, wind, and bioenergy. To ensure stability, it is crucial to integrate energy-storage technologies with grid enhancements. Therefore, policies should be implemented to incentivize the adoption of green energy. Fostering global cooperation and encouraging collaboration between the public and private sectors are essential to drive innovation. To create a sustainable and clean energy environment, studies should be conducted to explore sustainable energy methods in different sectors. With this in mind, the following proposition is proposed:

Proposition 4a: Further studies should investigate how liquidity, geopolitical risk, and fluctuations in economic policy affect the demand for green bonds and renewable energy stocks among portfolio investors.

Proposition 4b: Policymakers should consider incorporating clean and green energy stocks as related assets within their framework because renewable energy stocks substantially influence green bonds.

Future Directions for Cluster #5

Cluster 5's future trajectories should place increased emphasis on fostering global collaboration to establish consistent sustainability standards in the realm of sustainable finance. Future research endeavours should develop ground-breaking financial tools and mechanisms to facilitate sustainable development and foster green investments. It is paramount to conduct additional studies on the social impact of sustainable finance and strategies to enhance financial literacy within this framework. Financial decision-making should prioritize integrating environmental, social, and governance (ESG) factors. Therefore, the following propositions are proposed:

Proposition 5a: How can forward-thinking financial instruments effectively incentivize and promote sustainable investment?

Proposition 5b: What are the broader societal ramifications and consequences of sustainable financing?

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Proposition 5c: How can informed and sustainable finance decisions be accessible to a broader audience, and how can financial literacy be fostered?

Proposition 5d: Should further integration of Environmental, Social, and Governance (ESG) factors be implemented in financial decision-making?

Future Directions for Cluster #6

The sixth cluster revolves around the interconnection between green finance and banking. The emphasis is placed on the involvement of central banks in formulating monetary policies and macro-prudential regulations. Extensive deliberations have been made regarding the legal foundations required for the effective functioning of climate finance. Researchers have acknowledged China as a trailblazer in developing green investment policies (Larsen, 2022). Discussions have also occurred concerning the barriers and enablers of sustainable finance Cheung et al. (2022), as well as the role of central banks in shaping monetary policies to combat climate change (Boneva et al., 2022). While this section primarily addresses issues related to monetary policy, Cluster 6 covers the broader topic of public policy. The propositions are as follows:

Proposition 6a: To what extent is monetary policy involved in climate-financing initiatives?

Proposition 6b: Should climate financing policies be distinguished from monetary policy?

Future Directions for Cluster #7

Cluster 7 must prioritize interdisciplinary collaboration to confront intricate environmental challenges and explicitly advance green research. Primary research areas should focus on developing climate adaptation strategies, fostering sustainable resource management, and promoting renewable energy technologies. Enhancing data collection, analysis, and modelling methods is imperative for promoting innovation. Moreover, further research should delve into the socioeconomic implications of green initiatives and explore methods for integrating policies to provide holistic solutions for sustainability. The proposed questions are as follows.

Proposition 7a: Are interdisciplinary collaborations indispensable for effectively addressing complex environmental challenges?

Proposition 7b: How can advanced renewable energy technologies ensure a sustainable future?

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

Proposition 7c: Which sustainable practices should be adopted to manage and conserve resources effectively?

Proposition 7d: Which strategies can be studied to promote climate adaptation and resilience?

Proposition 7e: What are the socioeconomic consequences of implementing green initiatives, and how can inclusivity be guaranteed?

RESULTS AND DISCUSSION

This study offers a theoretical framework for examining climate finance in various sectors, making a significant contribution to the existing scientific literature, particularly in the finance and education fields. Building upon previous perspectives and insights, this research enhances our understanding of the intricate nature of climate finance and its impact on investment and educational practices. An important strength of this study is its utilization of bibliometric analysis, which allows for a systematic examination of the most influential studies in this field. Through an analysis of citations and co-citations, this study identifies key contributions and establishes the interconnectedness of ideas within the realm of climate finance. This approach highlights foundational research and provides valuable updates on the current research possibilities and emerging trends.

The primary focus of our research question revolves around the dispersion of climate finance research, considering the number of publications per year and research field from 2003 to 2023. These discoveries indicate a consistent rise in the number of scholarly articles devoted to climate finance each year, supported by numerous citations illuminating the significance of the study. This indicates that climate finance has strong linkages with diverse research domains, suggesting its multidisciplinary nature.

The second research concern revolves around the notable contributions and innovative advancements made by prominent authors, leading countries, reputable journals, and esteemed publications in climate finance research. Our findings revealed that Farhad Taghi-Zadeh-Hesary emerged as the most prolific author in this field, having published an impressive count of 20 articles. Regarding country-specific contributions, China stood out, with a remarkable total of 742 articles on climate finance. It is worth noting that climate finance articles are distributed across financial and economic journals, further emphasizing the necessity for researchers to adopt interdisciplinary approaches for conducting climate finance research. Integrating insights and knowledge from both domains can provide a more comprehensive understanding. This study also introduced a meticulous and all-encompassing methodology to identify and assess the most significant studies on climate finance. Zerbib (2019) as well as Taghizadeh-Hesary and Yoshino (2019) occupied the top positions in the citation list, with 500 and 368

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

citations, respectively. Furthermore Reboredo (2018) garners significant recognition with 334 citations.

The third research question concerns the enhancement of co-citation investigations to yield significant clusters. A thematic analysis uncovered seven distinct clusters, each examining a unique facet of climate finance, ranging from its conceptualization to the methodologies employed and its application within the financial system. Furthermore, it reveals the interconnections among these clusters and advocates for improved methodologies that would result in more effective implementation of climate finance in financial and educational settings.

The fourth research issue pertains to the dynamic aspects of the climate finance research field, encompassing the areas currently experiencing the most significant activity, recent trends in research, and emerging themes. Several active areas, recent trends, and emerging themes have been recognized, including green finance, green innovation, sustainable finance, digital finance, and technological innovation. A comprehensive analysis of the co-occurrence of keywords through an overlay visualization map clearly illustrates the interconnectedness of these subjects, which are commonly explored in research. Through this analysis, the map identified the prominent research topics of the year. Notably, the realm of climate finance has garnered significant attention from researchers, signifying its importance and relevance in contemporary scholarly discourse.

This research represents a remarkable advancement in the field of climate finance, as it introduces a comprehensive theoretical framework that draws insights from diverse sectors. Employing bibliometric analysis consolidates the existing knowledge and paves the way for future investigation and exploration. This study advocates a comprehensive approach to addressing climate challenges and promoting sustainability in these domains by forging a connection between finance, education, and climate change.

CONCLUSION

In this study, we conducted a bibliometric analysis to examine climate finance literature for 20 years (2003–2023). New scientific studies on climate finance have been published each year, and we analysed their citations to assess their relevance. Our findings highlight the significant contributions of prolific authors, countries, scientific journals, and studies in the financial and educational sectors to climate finance research, providing a comprehensive overview of the key hubs of research activity. Furthermore, we emphasize the importance of exploring all seven identified clusters of climate finance in the current research, namely, Green Bonds, Green Innovation, Green Finance, Green Energy, Sustainable Finance, Green Banking, and Green Research. Considering these clusters, researchers are provided with a wide range of options to

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

investigate, enabling a deeper understanding of the gaps in knowledge, technical expertise, skill sets, innovation, and implementation within climate finance.

This study encourages scholars to conduct thorough and rigorous scientific literature reviews incorporating bibliometric techniques, meta-analyses, and literature reviews. In future research, it is crucial to focus on evaluating the effectiveness of climate finance interventions, understanding the involvement of the private sector, and exploring the role of finance at the local and community levels in climate adaptation and mitigation. Beyond the academic sphere, the significance of this study extends to policymakers, financial institutions, and stakeholders involved in climate finance. It provides valuable guidelines for informed decisions and strategic planning, ultimately contributing to a more sustainable and climate-resilient future. As the challenges of climate change continue to increase, this study emphasizes the urgency of the climate crisis and underscores the necessity of research in creating a sustainable world.

Numerous limitations of this study should be considered when interpreting its findings. First, the reliability and accuracy of the data sources used in bibliometric analysis can introduce bias and incomplete information. Second, the scope of this study may not encompass all relevant climate finance literature, consequently neglecting important contributions. Moreover, the analysis primarily focused on quantitative metrics, potentially overlooking the intricate qualitative aspects of climate finance research. Furthermore, after the data cut-off date, the study may not have considered recent developments or changes in the climate finance sector. Lastly, this study acknowledges research gaps but does not offer an extensive qualitative analysis or policy recommendations to address them.

Based on the findings of this study, the following recommendations are proposed:

1. It is recommended that collaboration between renowned authors and esteemed institutions in the field be encouraged to foster the exchange of information and advance novel approaches to climate finance.
2. To gain valuable insights into the efficacy of funding programs, it is essential to promote research evaluating the practical impact of climate finance interventions in the real world.
3. Studies and initiatives that explore the role of local and community finances are encouraged to enhance grassroots climate resilience and adaptation.
4. Investing in ongoing research initiatives that focus on emerging fields is crucial to ensuring the adaptability of climate financing policies to emerging opportunities and challenges.

Vol: 16 **No:** 01 **Year:** 2024 **ISSN:** 1309-8055 (Online) (**pp.** 103-132) **Doi:** 10.34109/ijefs.202416105

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