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Analysis of Research Hotspots, Current Status, and Trends of Green Bonds: A Bibliometric Analysis based on WOS and CiteSpace

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Abstract

This paper uses bibliometric analysis to systematically review the current status, research hotspots, and development trends of green bonds, in order to provide references for future research on green bonds. Based on the relevant literature of green bonds in the Web of Science core collection from 2018 to 2022, CiteSpace software is used to analyze the annual frequency, publication journals, publish institutions, co-occurrence of keywords, citation frequency, and research frontiers of the relevant literature of green bonds. The results show that the research hotspots of green bonds are corporate social responsibility and debt, and the number of publications and citation frequency of green bond literature are both showing an increasing trend. From the perspective of publishing institutions, universities are the main institutions. The centrality of investment, corporate social responsibility, and other keywords is relatively high, indicating that these research topics occupy an important position in green bonds. As the attention to green bonds gradually increases, the research perspective tends to be diversified, and corporate social responsibility will be the focus of future research. The research results can provide theoretical references for the further development of green bonds.

Keywords

Green Bonds; Knowledge Graph; Bibliometrics; Visualization; CiteSpace.

1. Introduction

With the acceleration of industrialization, issues related to environmental protection, green sustainable development, and high-quality development have been increasingly emphasized. Developing green bonds to provide funding for environmentally beneficial projects is beneficial for promoting harmonious economic and environmental development.

Currently, many scholars have conducted research on green bonds. Rasoulinezhad and Taghizadeh-Hesary (2022) [11]used the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model to examine the relationship between carbon dioxide emissions, energy efficiency, Green Energy Index (GEI), and green finance in the top ten economies supporting green finance. The results show that green bonds are an appropriate way to promote green energy projects and significantly reduce carbon dioxide emissions. Zhou and Cui (2019)[21] studied the Chinese listed companies that issued green bonds to explore the impact of green bond issuance on the company, including the impact of the green bond issuance announcement on the company's stock price. Overall, the issuance of green bonds has a positive impact on the company, contributes to environmental improvement, promotes corporate social responsibility and value creation, and to some extent, helps attract investors. Abuzayed and Al-Fayoumi (2022)[1] investigated whether investors can obtain potential diversification or hedging benefits from holding green bonds in investment portfolios containing traditional financial assets during the COVID-19 pandemic. Their study shows that green bonds can bring

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significant diversification benefits to investors holding clean energy, global stock, and commodity assets. Existing literature has studied green innovation from different perspectives, but there are fewer studies from the perspective of bibliometrics. Therefore, this paper uses quantitative methods and techniques such as bibliometrics and knowledge graphs to systematically sort out domestic and foreign research progress based on published literature, draw a visual knowledge map of relevant literature, and intuitively reveal the research progress and development trends of green bonds, providing a reference for future green bond research.

Bibliometrics is a branch of library and information science that uses mathematical and applied statistical methods to describe, evaluate, and predict the current status and development trends of scientific and technological research based on the number of published literature. To effectively understand the research trend of green bonds in recent years, this paper analyzes the research progress of green bond based on literature published in the Web of Science Core Collection database (WOS) from 2008 to 2022. Through drawing related literature knowledge maps, visual representation of abstract literature data is achieved. The annual frequency, publication journals, publication institutions, co-occurrence of keywords, literature co-citation, and research frontiers of relevant literature are analyzed using bibliometrics and applied statistical methods, and a visual knowledge map of green bond research is drawn using Cite Space software. By systematically sorting out the research status and development trend of green bonds, this paper provides a reference for further green bond research.

2. Data Sources and Research Methods

According to Bradford's Law, core journals concentrate the core literature in research fields. The data for this study is derived from the Web of Science (WOS) core collection database, launched by the American Institute of Scientific Information. The search query used to retrieve literature data was "TS=Green bonds," with the literature types set to "Article" and "Review." The time span for the search was from 2008 to 2022 (as shown in Table 1). After using the Statistical Analysis of Title and Title Abbreviation Information (SATI) tool to remove duplicates from the literature bibliography information, 293 valid papers were obtained.

Table 1. Literature Retrieval Identification

Identification	Name	WOS Retrieval Instructions
Se	Search Query	Ts=Green bonds
Ts	Time Span	2008-2022
Dt	Document Type	Article, Review
Ds	Data Source	Web of science Core Collection Database

2.1. Research Methods

With the development of information technology, the sources of information have become increasingly vast, and big data analysis software has been applied in various fields of study to understand the research directions, authors, and institutions of the relevant research areas. Literature analysis is a tool based on statistical and quantitative analysis methods for studying published literature, which can make information visual. In this paper, we comprehensively used CiteSpace visualization software to conduct bibliometric analysis and draw literature knowledge maps.

CiteSpace software is developed based on the Java programming language and has powerful knowledge map drawing functions. CiteSpace is a multi-dimensional, temporal, and dynamic visualization software that combines social network analysis, association rule analysis, and other methods. It can analyze the development dynamics of research fields through knowledge

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map analysis and explore the evolving trends of research topics, research hotspots, and so on. The quantitative analysis process of green bonds is shown in Figure 1.

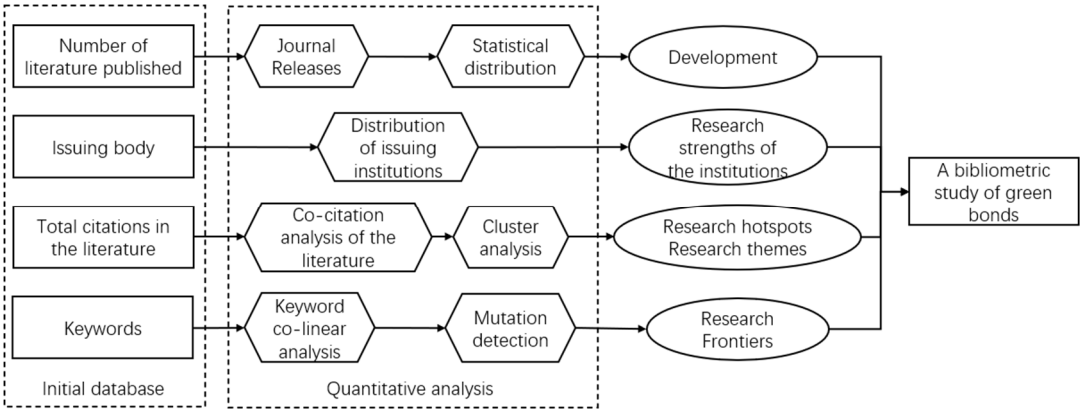

Figure 1. Quantitative analysis process for green bonds

Based on the literature metrics and relevant statistical methods, a total of 293 literature sources were retrieved and compiled as the database for green bonds. The Cite Space software was used to conduct visual analysis on the literature database, including the analysis of development trends, institutional distribution, co-occurrence of keywords, cited literature, and research frontiers. The visualization analysis provided insights into the evolution of research on green bonds, hotspots, and potential issues. The selection criteria for evaluation indicators are explained as follows.

1) Development trends. The number of literature sources to some extent represents the academic community's attention and importance to the research field. Using the citation analysis report function of the Web of Science database, the number of publications and citation frequency of literature sources can be obtained. By analyzing the time-series distribution of these data, the development trends of green bonds research can be inferred.

2) Research strength of institutions. Based on the literature sources retrieved from the Web of Science database, the Cite Space software was used to analyze the institutions publishing the literature. By drawing a co-occurrence knowledge map of institutions, the number of publications and other parameters of research institutions in the field of green bonds were obtained to analyze their collaborative relationships.

3) Research hotspots and topics. Keywords are highly condensed representations of the research content of literature sources. The analysis of high-frequency keyword co-occurrence can provide insights into research hotspots. The centrality can reflect the importance and connectivity of keyword nodes in a specific research field, indicating whether the high-frequency keywords are in a central position and reflecting their status in the overall network.

4) Research frontiers. The concept of "research frontiers" is used to reveal the dynamic evolution of the research field, defining a group of emergent concepts in a specific field as "research frontiers". Using the word frequency detection technology of Cite Space, high-frequency keywords with high frequency change rates were identified by analyzing the time distribution of keywords, and the frontier areas and development trends were determined based on the changing trends of word frequency.

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3. Results and Analysis

3.1. Time-series Analysis of Literature Quantity

According to the citation analysis report in the Web of Science database, the total number of published articles on green bonds was 293, with an average of 28 publications per year. The specific distribution is shown in Figure 2.

As shown in Figure 2, the publication of literature related to green bonds has been on the rise from 2008 to 2022, indicating a steady progression in the establishment of the research system and an increase in research on green bonds. The research on green bonds can be divided into two stages: steady growth and rapid growth. During the steady growth stage (2008-2018), the number of publications showed fluctuating growth and was relatively low at first, but then continued to increase, with small year-to-year differences. During the rapid growth stage (2019-2022), the increase in the number of publications was significantly higher than in the first stage, and the turning point was in 2018. The number of published articles reached its peak in 2022, with 132 articles, indicating that research on green bonds has been a focus of attention for experts and scholars. The frequency of citation of literature on green bonds has shown a significant upward trend from 2008 to 2022. Based on the above analysis, it can be concluded that research on green bonds is still receiving widespread attention and has good research prospects.

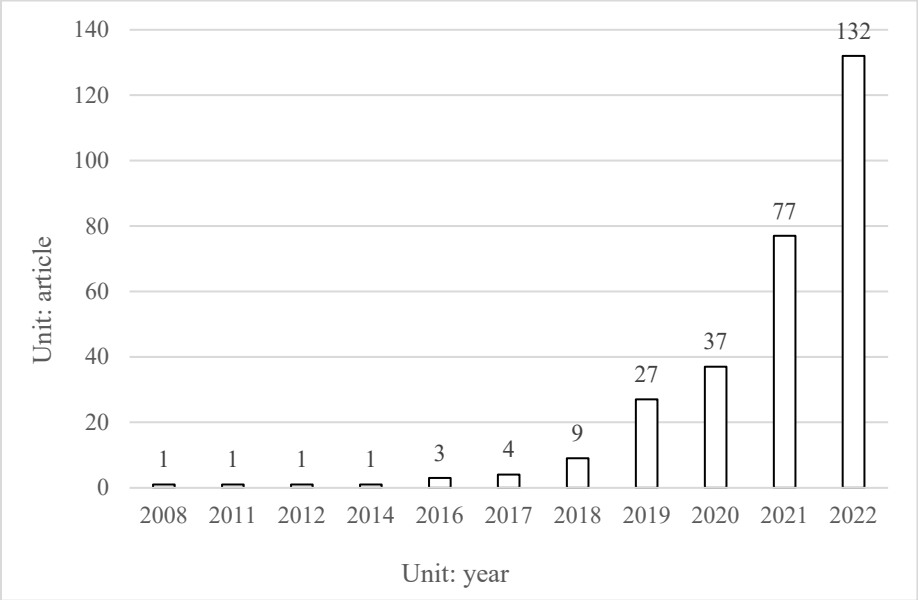

Figure 2. Bar chart of publication distribution.

Figure 3. Knowledge Map of Journals by Citations

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Using CiteSpace to extract data on journal sources, the highest ranked journal is "Journal of Cleaner Production" with 163 citations, followed by "Journal of Banking & Finance" with 161 citations, and "Energy Economics" in third place with 157 citations. The journals mainly cover topics such as clean production, banking and finance, and energy economics.

3.2. Institution Analysis

To further understand the research status and actual contribution of institutions in the field of green bonds, the publication volume of each research institution was counted. Based on the 293 publications as basic information, in Cite Space software, the network nodes were set as "Institution," the threshold was set to "Top25," and the network was pruned using the Minimum Spanning Tree (MST) algorithm. The advantage of MST is that it is computationally efficient and can quickly calculate results. The time span was set from 2008 to 2022, and considering that segmenting the data can improve the software's running speed and accuracy, the time slice was set to 1 year, which means it was divided into 12 time periods for analysis. The distribution of the number of publications by institution is shown in Figure 4.

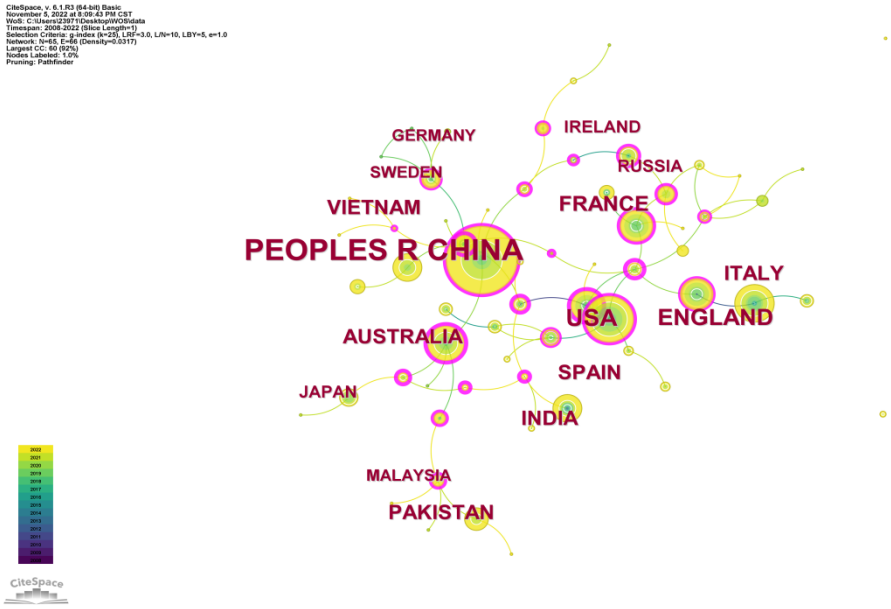

Figure 4. Institution distribution knowledge map

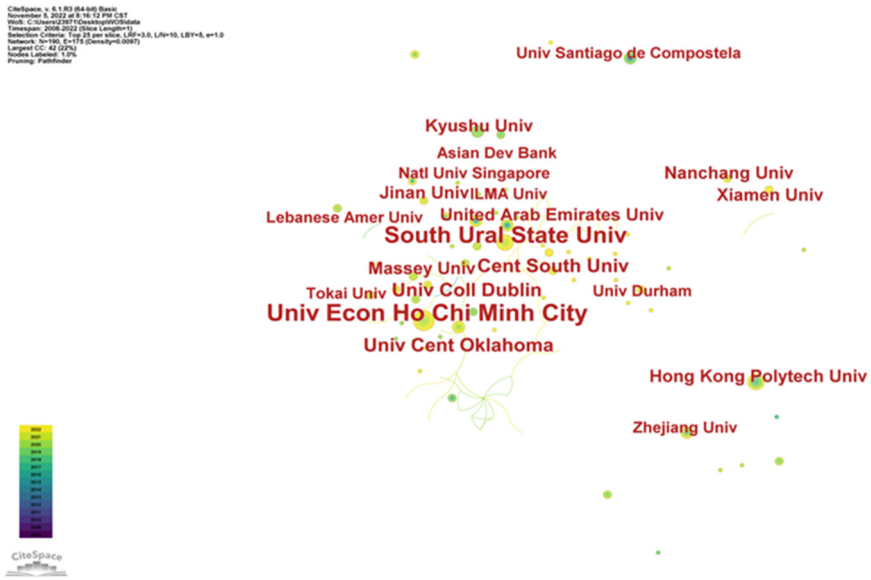

Figure 5. Knowledge map of countries publishing in the field of green bonds

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From the figure, it can be seen that research on green bonds involves a total of 166 institutions in the Web of Science Core Collection database, with publishing institutions mainly concentrated in universities and relatively concentrated. Univ Econ Ho Chi Minh City plays a pivotal role in research in this field. In terms of geographic distribution, publishing institutions are mainly located in China, followed by the United States. In terms of network cooperation, there are certain cooperative relationships among various research institutions.

3.3. Keyword Co-occurrence Analysis

Using Cite Space software for keyword co-occurrence analysis, snapshots of certain regions can be captured based on the time series, which can infer the research direction, trend changes, and research characteristics of the research field. The basic information of 293 documents was transferred to Cite Space for keyword analysis. After running and merging synonyms, a co-occurrence map of the main topics was obtained, as shown in Figure 6.

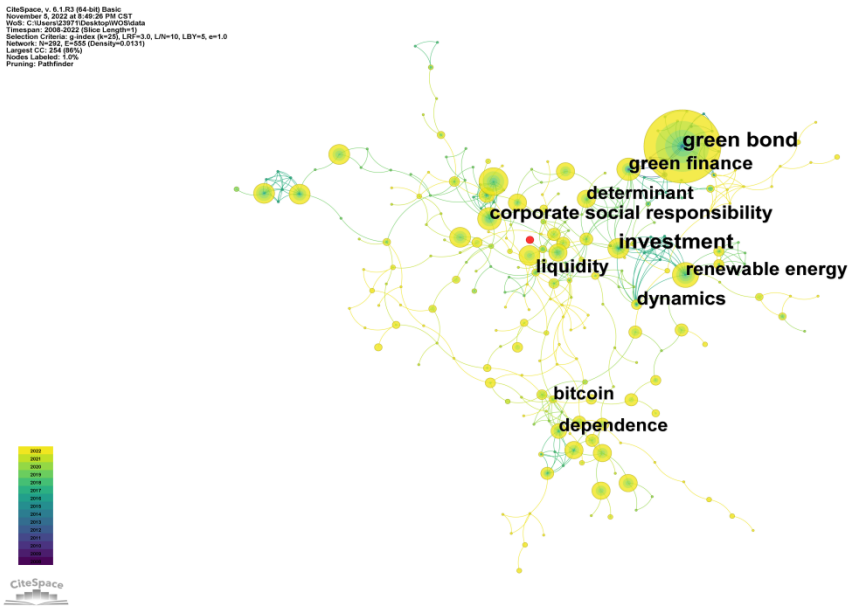

Figure 6. Keyword Co-occurrence Knowledge Map

The density of the co-occurrence map is calculated based on the analysis of the literature data using Cite Space software, and it can be seen from Figure 4 that the density of the map is 0.0131, indicating that the keyword co-occurrence map is relatively sparse and the research direction tends to be dispersed. There are a total of 292 nodes and 555 connecting lines in the figure, and the top 20 keywords with high frequency are selected, and their related information is obtained using Cite Space software, as shown in Table 2.

From analyzing the co-occurrence map of the theme words and Table 2, it can be seen that, apart from the search terms, nodes such as Green finance, Renewable energy, Investment, Corporate social responsibility, Cost, and volatility are relatively large, indicating that these theme words have a high frequency of occurrence and represent the research hotspots of green bonds. The centrality of Investment, Corporate social responsibility, Cost, and Green finance nodes is high, indicating that these research topics occupy an important position in the study of green bonds and are the "bridge" of research hotspots. The Debt node has a central position in red, representing the future development trend of the green bond research field.

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Table 2. Top 20 keywords ranked by centrality

Rank	Frequency	Betweenness Centrality	First Appearance Year	Keyword
1	24	0.4	2017	Investment
2	22	0.37	2018	Corporate social responsibility
3	20	0.32	2019	Cost
4	32	0.22	2012	Green finance
5	17	0.22	2017	Governance
6	1	0.2	2019	Corporate performance
7	5	0.19	2020	Bitcoin
8	4	0.18	2021	Credit
9	8	0.17	2019	Innovation
10	8	0.16	2019	Financial performance
11	8	0.16	2019	liquidity
12	4	0.16	2021	power
13	2	0.16	2022	Firm value
14	7	0.15	2019	Conventional bond
15	25	0.14	2017	Renewable energy
16	205	0.13	2012	Green bond
17	20	0.13	2020	Volatility
18	15	0.13	2019	Sustainable development
19	14	0.13	2018	Dependence
20	4	0.13	2020	Management

3.4. Co-citation Analysis

Co-cited literature refers to literature that shares common research content and references. In scientific mapping, co-cited literature contains a large amount of scientific knowledge. Co-cited literature can effectively expand research on the knowledge structure of the green bond research field. The number of citations is an important indicator for measuring academic influence, and can trace the research evolution process of disciplinary fields through literature. The more co-cited literature there is, the greater the correlation between the literature. Co-citation analysis is a relevant analysis of co-cited literature. In Cite Space, the network nodes are set as references, and the co-citation network map of the literature is obtained, as shown in Figure 7.

In the co-citation knowledge map of the literature, the larger the node, the more times it has been cited. The color at the top of the graph represents the corresponding year in which the literature is presented in the map. Some nodes have purple and red circles at the outermost layer corresponding to the year, which represents the centrality of the node. For example, the node of Zerbib (2019)[20], the thicker the purple and red circle, the stronger the importance of the literature. Through the analysis of key nodes in the map, it can be seen that there are two large nodes in the graph, indicating that these two articles have been cited more and have a greater impact on the green bond research field. The first authors of these two articles are Zerbib (2019)[20] and Reboredo (2018)[12], respectively. The most frequently cited article is Zerbib's article published in the Journal of Banking & Finance in 2019. The article uses green bonds as a tool to determine the non-monetary motives, especially environmental preferences, on the bond market price. The results show that the yield of green bonds is lower than that of

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traditional bonds. This negative premium is more pronounced for financial and low-rated bonds. The results emphasize that investors' environmental preferences have little impact on bond prices, but at present, this does not represent the positive support of investors for the expansion of the green bond market. Based on the co-citation network map of the literature, a clustering analysis of the literature is performed, and the clustering results are shown in Figure 8.

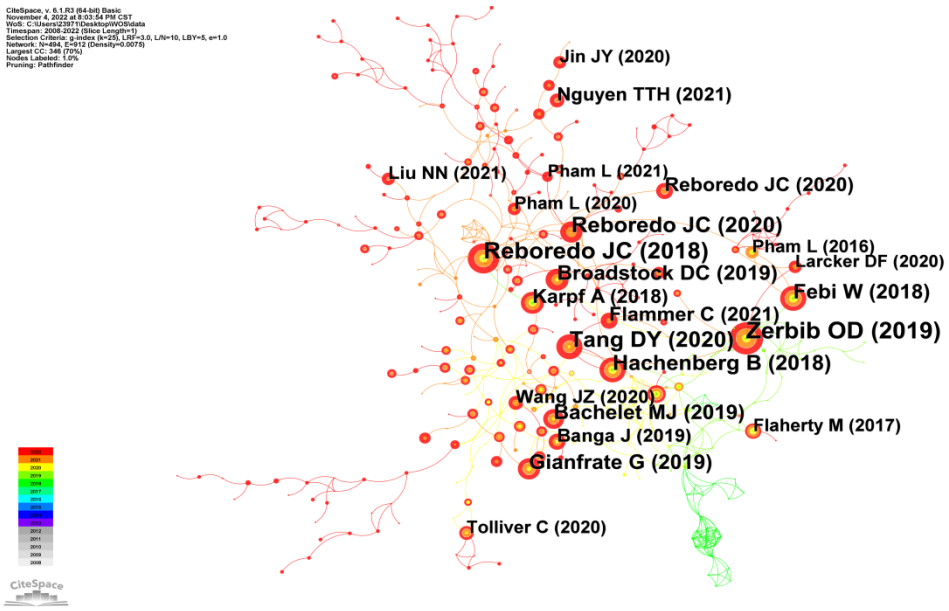

Figure 7. Knowledge graph of literature co-citations

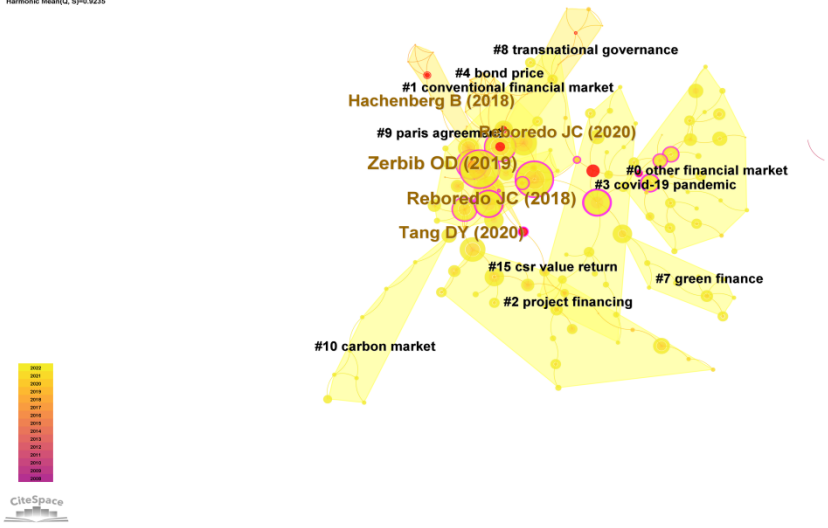

Figure 8. Is a knowledge map of the research topics of co-cited references.

It can be seen from Figure 8 that the network consists of 220 nodes and 317 links. The clustering results are evaluated using the modularity (Q value) and average silhouette value (S value) of the clustering module. Generally speaking, when the Q value is in the range of [0,1), a Q value greater than 0.3 indicates that the community structure is significant. As shown in Figure 6, the Q value of this clustering result is 0.8921, which is greater than 0.3, indicating that the community structure of this clustering result is significant. Further analysis shows that the

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clustering results include 10 clusters, #0, #1, #2, #3, #4, #7, #8, #9, #10, and #15. Therefore, based on the co-cited references, green bonds can be divided into 10 research categories: Other Financial Market, Conventional Financial Market, Project Financing, Covid-19 Pandemic, Bond Price and Green Finance, Transnational Governance, Paris Agreement, Carbon Market, and Csr Value Return. Other Financial Market and Conventional Financial Market may be the main research directions in this field, while Project Financing, Bond Price, Green Finance, Carbon Market, and Csr Value Return may be the main research branches. Covid-19 Pandemic, Transnational Governance, and Paris Agreement may be nodes that have emerged due to recent events in this field.

Table 3. Summary of the largest 5 clusters

Cluster ID	Size	Silhouette	Label (LLR)	Representative publication
#0	30	0.982	other financial market	Ul, haq I (2022); Nguyen TTH(2021); Wang JZ(2020); Liu NN(2021)
#1	23	0.924	conventional financial market	Akhtaruzzaman, M (2022); Zerbib OD(2019); Tang DY,(2020); Hachenberg B(2018)
#2	20	0.948	project financing	Yadav, M (2022) ; Gianfrate G(2019); Banga J(2019); Tolliver C(2020)
#3	19	0.969	covid-19 pandemic	Debrah, C (2022), Reboredo JC(2020); Pham L(2020)
#4	13	0.954	bond price	Zerbib, OD(2019), Reboredo JC (2018), Febi W(2018), Karpf A(2018)

Cluster #0: Other financial market. In a seminal study, Ul et al. (2022)[17] used a partial wavelet coherence framework to capture binary comovement and demonstrated strong (weak) positive comovement between green bonds and the Dow Jones Sustainability World Index returns, with green bonds exhibiting heterogeneous dominance in both short and long-term ranges. Results showed moderate positive (negative) synergies between green bonds and sustainable cryptocurrencies (Bitcoin) and the Dow Jones Sustainability World Index from a short-term (long-term) perspective. Nguyen et al. (2021)[15] investigated the interrelationships between green bonds and other asset markets (including stocks, commodities, clean energy, and traditional bonds) from 2008 to 2019, spanning 11 years. They evaluated the dynamic correlation features between assets at different times and frequencies using a rolling-window wavelet correlation method and found that most of the correlations emerged and peaked after the global financial crisis of 2007-2009. Despite the relatively high synergy between stocks, commodities, and clean energy, the diversification benefits of green bonds were evident due to their low or negative correlations with stocks and commodities. Wang et al. (2020)[18] provided the first evidence of the response of the debt and stock markets of China, the largest developing economy and largest emerging debt market, to the issuance of corporate green bonds. For new issuances by high Corporate Social Responsibility (CSR) issuers and

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underwriters, the pricing premium of corporate green bonds was most apparent, and this was also stronger for issuers with low ownership concentration and held by long-term institutional investors. Further analysis showed that the stock return of new green bond issuances was positive, consistent with stakeholder value maximization theory, indicating that participation in sustainable financing practices would increase corporate value in the long run and be favored by shareholders. Liu et al. (2021)[10] empirically analyzed the positive time-varying mean and tail correlations between green bonds and the clean energy stock market. In addition, extreme drops or rises in the clean energy stock market could spill over to the green bond market and vice versa, and the risk spillover between these markets was asymmetric. These results have important implications for policymakers and environmentally responsible investors holding green bond positions by increasing unexpected tail losses.

Cluster#1: Conventional financial market. In a representative literature, Akhtaruzzaman et al. (2022)[2] investigated the role of green bonds in hedging industry portfolios and other major asset class risks. The results indicate that the risk of green investment portfolios is lower than that of unhedged (non-green) investment portfolios. Furthermore, investors with risk aversion preferences gain higher utility when investing in green investment portfolios after considering transaction costs. Zerbib (2019)[20] examined the yield premium of green bonds. The results show that the yield of green bonds is lower than that of conventional bonds. Tang and Zhang (2020)[14] conducted an empirical study for the first time on the announcement return and actual effect of companies issuing green bonds in 28 countries from 2007 to 2017. No significant sustained premium of green bonds was found, indicating that the positive stock return brought by the announcement of green bonds is not entirely driven by lower debt costs. Institutional ownership, especially from domestic institutions, increased after the issuance of green bonds. Stock liquidity improved significantly after the issuance of green bonds. Overall, the issuance of green bonds by the company is beneficial to its existing shareholders. Hachenberg and Schiereck (2018)[7] used green bonds as a tool to determine the impact of non-monetary motives, especially environmental preferences, on bond market prices. The results show that the yield of green bonds is lower than that of traditional bonds. This negative premium is more pronounced for financial and low-rated bonds.

Cluster #2: Project financing. In representative literature, Yadav et al. (2022)[19] studied the dynamic linkages between green bonds and the European financial markets. Evidence from this study suggests that green bonds are only included in these financial markets for a short period of time; the findings are expected to have practical implications for portfolio managers, investors, and market regulators, and suggest that green bonds should be included in investors' portfolios to effectively diversify risk. Gianfrate and Peri (2019)[6] studied 121 European green bonds issued between 2013 and 2017 and found that green bonds are more financially convenient than non-green bonds. The advantages to the issuing companies are greater, and they continue to exist in the secondary market. Banga (2019)[3] explored the potential of green bonds in mobilizing funds for adaptation and mitigation in developing countries. The results suggest that the rise of green bonds is a fact in both developed and emerging countries, driven by investors' increasing climate awareness. Tolliver et al. (2020)[16] found that national contributions and other macroeconomic and institutional factors are driving the growth of green bond issuance, which will provide funding for future climate and sustainability investments.

Cluster #3: COVID-19 pandemic. In a representative study, Debrah et al. (2022)[4] found that green finance is still a relatively immature but interdisciplinary research field. Reboredo and Ugolini (2020)[13] used a vector autoregression (VAR) model to examine the price correlation between the green bond market and financial markets. Empirical results showed that the green bond market is closely related to fixed income and currency markets, obtaining significant price excess returns from these markets, and transmitting negligible reverse effects. In contrast, the

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green bond market has weaker connections with stock, energy, and high-yield corporate bond markets. Pham and Huynh (2020)[9] empirically studied the relationship between investor attention and green bond market performance. After using daily data on investor attention and the green bond index, they found that investor attention can affect green bond yield and volatility, but the relationship is time-varying. Their research results are relevant to investors because they reveal the emerging and rapidly growing green bond market.

Cluster #4: Bond price. In a representative study, Zerbib (2019)[20] used green bonds as a tool to determine the impact of non-monetary motivations, especially environmental preferences, on bond market prices. The results showed that the yield of green bonds is lower than that of traditional bonds. Reboredo (2018)[12] studied the co-movement between the green bond market and financial markets and found that the green bond market is coupled with corporate and government bond markets, and has weaker co-movement with stock and energy commodity markets. Diversified returns of green bonds are insignificant for investors in corporate and government bond markets, but significant for investors in stock and energy markets. Febi et al. (2018)[5] analyzed how liquidity risk affects bond yield spreads after controlling for credit risk, bond-specific features, and macroeconomic variables. The study showed that the impact of liquidity on bond yields decreases over time, indicating that the liquidity risk of green bonds today can be ignored. Karpf and Mandel (2018)[8] studied the differences in yield curve structure between green bonds and traditional bonds in the US municipal bond market. They showed that although the average return of traditional bonds is higher than that of green bonds, the difference can largely be explained by the basic attributes of the bonds.

3.5. Analysis of the Frontiers in Research

Through keyword burst analysis, 11 keywords with burst occurrences were detected, as shown in Figure 9. Keywords with high burst intensity indicate emerging hotspots in the research field. Further analysis reveals that the keyword "debt" has the highest burst intensity of 3.97, followed by "corporate social responsibility" with a burst intensity of 1.94, indicating a higher correlation between green bonds research and corporate social responsibility from 2008 to 2022. "Safe haven" and "sustainability" both had burst occurrences in 2021-2022 and may become future research hotspots in the field of green bonds. Overall, the research perspective of green bonds was relatively rich from 2008 to 2022.

Top 11 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2008 - 2022
corporate social responsibility	2018	1.94	**2018**	2019	
debt	2019	3.97	**2019**	2020	
cost	2019	1.91	**2019**	2019	
bond yield	2019	1.61	**2019**	2019	
capital structure	2019	1.48	**2019**	2020	
volatility	2020	1.76	**2020**	2020	
market	2020	1.71	**2020**	2020	
risk	2020	1.61	**2020**	2020	
gold	2020	1.5	**2020**	2022	
safe haven	2021	1.77	**2021**	2022	
sustainability	2021	1.46	**2021**	2022	

Figure 9. High-frequency emerging keywords

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Note: The red line segment corresponds to the duration of the emerging period of the keyword; the blue line segment represents the other periods during the research period where there was no emergence.

4. Conclusion

Since 2008, the academic community's attention to green bonds research has gradually increased, and the field is currently receiving significant attention, generating many new research hotspots. The types of journals mainly focus on clean production, banking and finance, and energy economics, showing the characteristic of cross-disciplinary research. It is expected that the research on green bonds will continue to grow in the future. The first authors of the literature are mostly affiliated with universities, with the highest number of publications from the University of Economics Ho Chi Minh City, and there are significant differences between institutions. In the future, research institutions should strengthen team collaboration to create more innovative research results.

Corporate social responsibility and debt are high-frequency keywords that represent the research hotspots of green bonds. Investment and corporate social responsibility are high-degree centrality keywords, indicating that these research themes are important in the study of green bonds. Through the analysis of keyword bursts, it can be seen that in recent years, the research perspectives on green bonds have become more diverse, and corporate social responsibility will be a future research focus.

The world's environmental problems are increasingly prominent, and in order to achieve sustainable development goals, more and more countries are using green bonds financing to realize sustainable financing mechanisms. However, current literature mainly focuses on corporate social responsibility and investment, and the impact of green bond financing on environmental and social sustainability has not been confirmed. Therefore, from the perspective of solving practical problems, discussions can be held on how to improve environmental and social sustainability.

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