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# MEANINGFUL REVIEW OF EXISTING TRENDS, EXPANSION, AND FUTURE DIRECTIONS OF GREEN BOND RESEARCH: A BIBLIOMETRIC APPROACH

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**Abstract:** Green bonds serve as an imperative financial tool for mitigating climate change risk and environmental sustainability. It has received significant attention in the current literature, with increased worldwide efforts to fight against global climate change. Yet, the direction of green bonds' literature is currently unclear. Therefore, this paper aims to deliver a comprehensive vision of the literary landscape of green bond research, in consideration of policymakers, major market players, and investors. To achieve this, bibliometric analysis is performed on 342 filtered articles found in the Scopus database, through VOSviewer and Biblioshiny package. A detailed and descriptive evaluation of scholarly data demonstrates the significance of green bonds in accomplishing the objective of sustainable finance and

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mitigation of climate change. This study broadens our understanding of the literature and conceptual growth of scholarly discussion of green bonds, which gives insight into developing a strong conceptual foundation and future directions for research.

**Keywords:** Green bonds; climate change; Bibliometric analysis; conceptual structure; Mapping analysis; Sustainable financing.

**JEL Codes:** G11, G23, G32, G41, O13, O16, Q56.

## 1. Introduction

Climate change brought on by global warming is one of humanity's most serious problems during the twenty-first century (Climate Financial Risk Forum). Climate change is also posing serious financial consequences in the business world. Firms are also being impacted by this difficulty. There is currently a developing perspective on the significance of the financial risk related to climate change. Previous research outlines the three categories of financial risks linked to the climate: physical, liability, and transitional risks (NGFS, 2019). Physical risks such as storms and floods that disrupt trade could occur due to weather and climatic factors, while liability risks could come from those who have lost or incurred damages. The danger that might emerge as a result of the transition to a low-carbon economy is referred to as transitional risk (NGFS, 2019).

In light of global warming and other adverse changes in the climate, policymakers are inclined to create a green economy by connecting the financial markets with the economy and offering environmental-friendly financial assets (Agliardi & Agliardi, 2019). Investment in green projects and fossil fuels is seen as a key factor in achieving this purpose. For this reason, green bonds appear as a prominent means of financing green projects. This process enables environmental organizations to raise money by issuing financial instruments that are also used for environmentally friendly and sustainable projects (Park, 2018).

Green bonds are currently regarded as a new and innovative financing product used to finance initiatives that promote the adoption of the green economy (Banga, 2019). There is evidence that carbon emissions decreased following the issuance of green bonds, thus demonstrating that 'green bonds' are deployed as a tool to combat climate change (Fatica & Panzica, 2021).

Governments, financial institutions, and companies issue green bonds as a kind of financial instrument to finance environmentally friendly initiatives including those that use renewable energy, green building, low-carbon transportation, water conservation, and waste management. These projects help in reducing the adverse effects of economic activities on the climate (World Bank, 2021). Figure 1 shows the use of green bond proceeds on environment-friendly projects.

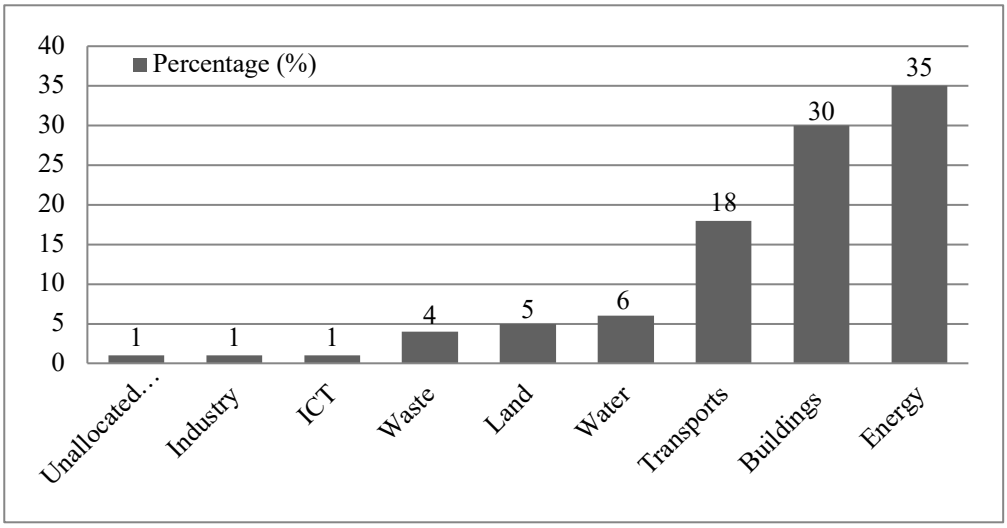


**Figure 1 Use of green bonds proceeds**
Source: Climate Bond Initiative.

Similar to traditional bonds, green bonds are debt instruments, but they are used to finance projects that contribute directly or indirectly to environmental protection. The use of green bonds proceeds sets them apart from conventional bonds (Mihálovits & Tapaszti, 2018). The earnings from green bonds go toward preserving natural resources, reducing climate change, and reducing environmental pollution (Broadstock & Cheng, 2019). Companies' CO2 emissions were reduced and their environmental rating increased after they issue green bonds, mitigating the effects of climate change (Flammer, 2021; Fatica & Panzica, 2021). Similarly, following the issuing of green bonds, corporate environmental and reputational risk also declined (Baulkaran, 2019).

The financial sector has a significant impact on funding and raising public awareness of sustainability-related issues. It can be done either through enabling the development of alternative energy sources or by assisting companies that employ ethical and environmental-friendly practices. Sustainable investment is defined as the investment decisions that consider an economic activity's environmental, social, and governance (ESG) issues (Bakken, 2021).

The development of green bonds and the expansion of the green bond market rank as two of the most significant financial changes in the field of sustainable finance during the past 10 years. They are considered a financial innovation intended to assist sustainable investing. Green bonds are also considered to be a well-known and low-

risk financial tool that enables issuers and investors to support sustainability goals at a reasonable cost (Maltais & Nykvist, 2020).

The first green bond, known as a Climate Awareness Bond, was issued by the European Investment Bank in 2007. Afterwards, the green bond market keeps expanding in terms of bonds issued and the widening of its geographic base. Poland released the first sovereign bond on the green bond market in 2016, followed by France and other countries. Between 2008 and 2021, green bonds worth USD 1.989 trillion were issued till the first quarter of 2022 (Climate Bond Initiative, 2022). Figure 2 highlights the overall green bond issuance volume.

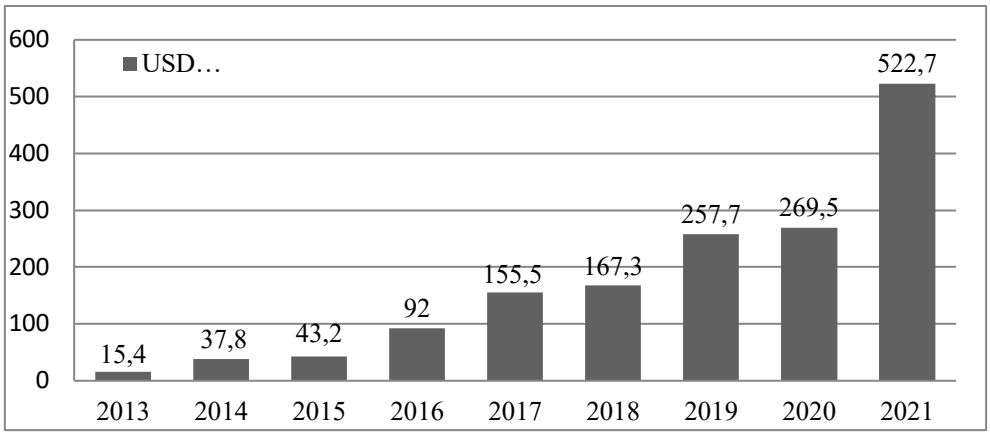


**Figure 2 Green bonds issuance volume**
Source: Climate bond initiative.

Since its inception, international organizations and national governments have been actively promoting green bonds, which is a clear indication of its key role in policy agenda-setting (International Capital Market Association). Academic researchers' interest in the topic has also grown. (Maltais & Nykvist, 2020) highlight the important role of green bonds in advancing sustainability. Green bonds are extensively mentioned in sustainable finance literature specifically in financial markets. It is reported that investors perceive the issuing of green bonds as a firm's effort to raise money from investors who have environmental, social, and governance (ESG) goals (Flammer, 2021; Tang & Zhang, 2020; Maltais & Nykvist, 2021; Verma & Bansal, 2021). Hence, investors are also aware of and value the company's ESG performance (Tang & Zhang, 2020). Relationships between the green bond market with financial and commodity markets are also observed (Naeem et al., 2021; Reboredo, 2018). Besides, green bonds are studied from the perspective of

sustainability, corporate social responsibility and the environment (Xiao et al., 2018; Flammer, 2015; Castro, 2021).

Despite the remarkable theoretical and empirical growth of green bond research, there are still large gaps in its practical application due to its complexity and multidimensionality. The fundamental question of how governments, international organizations, investors and business management may use the idea of green bonds to advance environmental sustainability, lessen the impact of climate change, and increase shareholder and firm wealth is still open to debate. However, with more attention being paid to environmental sustainability and climate change, the demand for using green bonds has gained larger consideration.

Hence, there is a need to explore the current status, scientific growth and future direction in literature. The development of extensive and fragmented streams has been influenced by the increasing emphasis on empirical research (Briner & Denyer, 2012), which is limiting this field's advancement to sound theoretical underpinnings. Because of this, literature reviews have begun to play an essential role in the integration of data from previous research to effectively use the body of existing information, progress a line of research, and provide evidence-based input into the use of professional decree and knowledge (Rousseau, 2012).

One of the reliable methods for assessing the literary landscapes in any field of study is bibliometric reviews (Donthu et al., 2021; Ruhanen et al., 2015). However, to the best of the researcher's knowledge, bibliometric studies on green bonds to explore the literature on the issues, current trends, and potential future directions in this significant area of study are missing. Even with the incredible expansion in the field of green bonds, the evaluated studies are still limited in scope. Therefore, this paper would address these issues by conducting a systematic and comprehensive bibliometric analysis of the literary landscape of green bonds research since its inception in 2007, in conjunction with various fields of research.

This paper begins by evaluating recent literature to first provide a comprehensive overview of significant scholarly research. By analyzing the current situation, we expect to gain a complete understanding of the conceptual problems, but more importantly, we hope to identify trends in development and provide useful guidance for future research in this significant and developing area. The structure of this paper is as follows. Section 2 covers the methodology and tools used for this paper. The findings analysis and discussion are presented in Section 3. The conclusion and recommendations for future research in green bonds are discussed in Section 4 of the study.

## 2. Methodology and tools

This study uses a bibliometric analysis approach. Pritchard (Pritchard, 1969) used bibliometric analysis for the first time, and since then it has grown widely in quantitative analysis to increase understanding of the literature. The bibliometric analysis is thought to be the most thorough and exact method for determining the current body of knowledge in any subject of study (Donthu et al., 2021; Ruhanen et al., 2015; Zupic & Čater, 2015). Unlike other techniques, bibliometric provides more objective and precise analysis (Aria & Cuccurullo, 2017), which brands itself as an essential tool for assessing and investigating the academic output of researchers, institutional cooperation, the effects of government financing on the efficiency of national research and development, and the productivity of academics (Moral-muñoz et al., 2020). The use of the bibliometric approach helps researchers in determining the crucial elements in a certain research stream (Secinaro et al., 2020). Because of its ability to evaluate literature using hundreds of papers to identify authors, countries of origin, crucial aspects and topics, research gaps, and areas of interest for future research, bibliometric analysis is regarded as an influential and rapid method (Iqbal et al., 2022; Verrall & Pickering, 2020). Additionally, bibliometric reviews are ideally appropriate for examining new tendencies in a subject (Pickering & Byrne, 2014), which is the reason why they were chosen as the best technique for this paper.

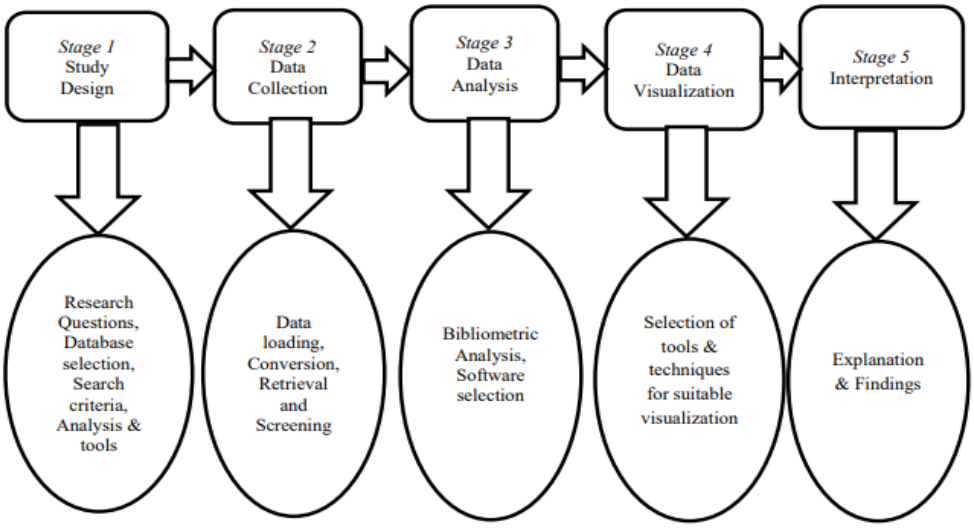


**Figure 3 Workflow of study stages**
Source: Own processing using the scholarly work.

This paper employs the standard science mapping workflow applied by numerous researchers in their research work (Aria & Cuccurullo, 2017; McCabe & Qiao, 2020; Xie et al., 2020; Zupic & Čater, 2015; Iqbal et al., 2022) which comprised five inclusive stages as shown in Figure 3.

Stage 1 of the workflow is the study design which includes research questions, database selection, search criteria and analysis tools selection. In this stage, research questions for this study were initially generated, the entire study was precisely prepared, and several criteria were developed to carry out the study in a methodical manner. For this purpose, the Scopus database was utilized as a database selection criterion. Scopus is an academic catalogue of peer-reviewed academic publications that provides comprehensive views of the research carried out globally, which is founded by Elsevier in 2004.

Next, a selection search criterion is determined, which includes the form of data to be extracted, query word selection, format compatibility of data extracted and time selection. The time selection for this study was taken from 2007, which is the first launching of green bonds to date (September 2022). An analysis tool was selected, and for this, Biblioshiny, a web-based R package from Bibliometrix 4.0.0 is used. Biblioshiny is one of the most powerful, popular, compatible and modern tools which is used to perform science mapping analysis comprehensively (Moral-muñoz et al., 2020; Aria & Cuccurullo, 2017). Major databases, such as Scopus, Web of Science (WoS) and Dimensions, operate well with this analysis tool (Moral-muñoz et al., 2020). Biblioshiny distinguished itself from all earlier established tools due to a wider variety of analyses that can be carried out along with the incorporation and combination of methods efficiently (Moral-muñoz et al., 2020; Secinaro et al., 2020; Xie et al., 2020). For the mapping of literature and data visualization, the VOSviewer is adopted. Using both Biblioshiny and VOSviewer, a variety of visual as well as descriptive analyses can be performed, including word clouds, three fields plots, co-citation analysis, co-words analysis, collaboration analysis, co-occurrence, and many others (Aria & Cuccurullo, 2017; Secinaro et al., 2020; Zupic & Čater, 2015).

Stage 2 of the workflow is data collection, which is considered one of the most important stages in the bibliometric study because the trustworthiness and scope of the whole study are based on the data. The Scopus database is used because it comprises data on all authors in cited sources, improving the accuracy of co-citation and citation analysis (Zupic & Čater, 2015). The selection of accurate and relevant target keywords/search phrases is another vital phase that alters the research scope. To provide a wider and more comprehensive picture of the scholarly work in the field, a variety of keywords/terms/phrases was used for the literature search, as indicated in Table 1.

**Table 1 Search approach**

| Sr. No | Types | Category |
|---|---|---|
| **1** | Search Query | TITLE-ABS-KEY ('green bonds' OR 'climate awareness bonds' OR 'corporate green bonds') |
| **2** | Period | 2017 to September 2022 |
| **3** | Subject area | All |
| **4** | Source type | Journal articles |
| **5** | Language | English |

Source: Own processing based on Biblioshiny tool using RStudio.

Furthermore, to focus on search and eradicate inappropriate research work, the 'OR' Boolean operator was used. It was decided for this study not to restrict the search to one particular subject area after carefully reviewing the search result because several studies were published in multidisciplinary journals. In the initial search, a total number of 493 published documents were identified. Initial searched documents were then filtered based on time, language, source type, and document type.

English is used as the language for the search query because it is easy to compare affiliations, articles sources and keywords using a variety of tools when a widely used language is applied (Nasir et al., 2020). Furthermore, the English language is also universally accepted in academic writing (Genc & Bada, 2010; Drubin & Kellogg, 2012). For document type, journal articles are selected due to the strict peer-reviewing method implemented by the journal to make sure the quality of publications (De la Cruz del Río-Rama et al., 2020; Niñerola et al., 2019; Secinaro et al., 2020; Zupic & Čater, 2015).

Besides, manual screening of the title of research papers, keywords and abstract was performed to enhance the inclusion of only relevant research articles for the analysis. After in-depth necessary limit and screening, a total of 342 research articles were included in the analysis, whereas 151 articles are excluded. Out of 151, 145 documents were excluded based on source and document type whereas 6 documents were excluded due to their irrelevancy.

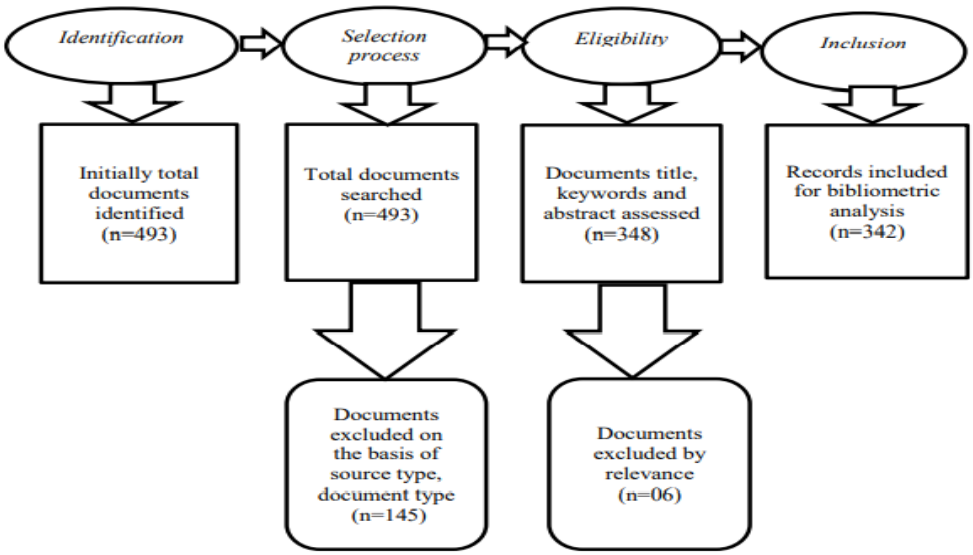


**Figure 4 PRISMA methods for data screening**
Source: Own processing using PRISMA methods.

This study followed the 'preferred reporting items for systematic reviews and meta-analysis (PRISMA)' method to screen research articles (De la Cruz del Río-Rama et al., 2020). The detail of the PRISMA method is shown in Figure 4.
Stage 3 of the workflow is descriptive data analysis of extracted data. It consists of top journals in the field, annual publications, citations, distinguished authors, main research areas, institutions and authors' countries' relevant data. Stage 4 of the workflow is data visualization, which involves network analysis by applying the VOSviewer and Biblioshiny tools. In this phase, cluster analysis, key-words analysis, thematic evolution analysis, co-citation analysis and collaboration mapping are carried out. In stage 5, which is the final stage of workflow, explanations and findings, are carried out based on network analysis as well as descriptive analysis. The main objective is to analyze the existing trends as well as the thematic evolution of the literature on green bonds.

## 3. Bibliometric analysis results and discussion

In this paper, literature is analyzed from different perspectives: trends of research articles published in journals, most prominent journals concerning contribution in

terms of numbers, and the most prominent publications that indicate the citation trend, to name a few. The detail of each analysis is discussed in the following section.

### 3.1 Development of green bonds literature

Descriptive statistics about green bond literature provide an insightful understanding. Table 2 depicts the growth of green bond literature in detail.

**Table 2 Descriptive statistics about 'green bonds' literature**

| Description | Results |
|---|---|
| Sources (Journals) | 154 |
| Documents | 342 |
| Annual growth rate % | 51.65 |
| Document average age | 1.11 |
| Average citations per document | 14.15 |
| References | 17072 |
| Keywords plus (ID) | 896 |
| Author's keywords (DE) | 967 |
| Authors | 772 |
| Documents per author | 0.443 |
| Authors of single-authored documents | 48 |
| Single-authored documents | 54 |
| Co-authors per documents | 2.87 |
| International co-authorships % | 37.13 |
| Article | 342 |

Source: Own processing based on Biblioshiny tool using RStudio.

From the 342 documents screened for this study, it can be traced to 154 sources that include journals only. A total number of 772 authors published these research papers. Also, 967 authors' keywords and 896 keywords plus are used by all of these journals. The author's keywords are determined by the authors themselves, whereas the keywords plus are generated automatically by a computer programme and consist of words that commonly appear in the titles of the article's references. Green bonds were introduced in 2007 but the first research paper on them was published in 2010 as per the Scopus database. Further, the average number of citations per document in the descriptive analysis is 14.15, which indicates that on average each document is cited 14 times. Out of 342, only 54 documents are single-authored. Descriptive

statistics further show that the ratio of documents per author is 0.443, indicating that one document is written by approximately 2 authors.

The annual scientific production and growth rate pattern of publications on green bonds are shown in Figure 5. Following the introduction of green bonds in 2007, the annual production was initially slow but later on, the annual production starts to increase with an annual growth rate of 51.65%. Historically, there was only one publication made in 2015, then 2 in 2016, 4 in 2017, 13 in 2018, 24 in 2019, 50 in 2020, 98 in 2021, and 148 until September 2022. These annual statistics clearly show a pronounced growth pattern of annual scientific production in the literature on green bonds.

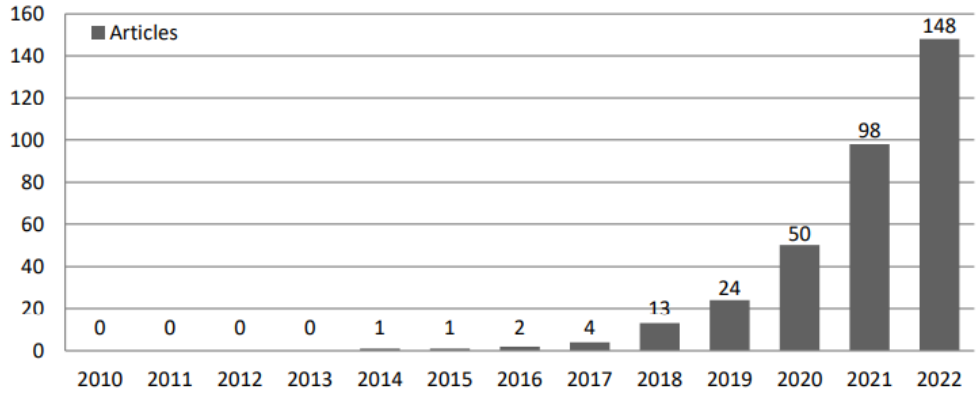


**Figure 5 Annual scientific production of green bonds literature**
Source: Own processing based on Biblioshiny tool using RStudio.

The increase in global climate change risk for the business world (Climate Financial Risk Forum, 2021) was the main reason for this sharp increase in annual scientific production because businesses started to face climate change risk, which ultimately encourages them to issue green bonds (Park, 2018). Figure 5 indicates that the increase in annual scientific production started when companies start to issue green bonds in 2013 (Flammer, 2021). The earnings from the issuance of green bonds were used for environmental projects to mitigate the climate change risk. It is also evidenced that companies' environmental performance increased, whereas CO2 emissions decreased after the issuance of green bonds (Flammer, 2021). Furthermore, the better environmental performance of the companies leads to an increase in the stock prices of firms (Castro, 2021). In sum, it can be inferred that the trend of academic research increased following the issuing of green bonds by the corporate sector. Accordingly, a sharp rise in average citations can also be observed.

The continuous progression trend in the average citation per year shows the importance of green bond research both empirically and practically.

Following a thorough review of annual scientific production, it is important to understand the fundamental concepts, countries, and affiliations of the research publications on green bonds. Figure 6 illustrates the three-field plot of green bond publications, which includes the affiliations of the authors on the right, the countries of the authors in the middle, and keywords plus on the left. It demonstrates that authors from China are in a leading position concerning green bond publications. It shows that China is working with a maximum number of top affiliations regarding green bond publications.

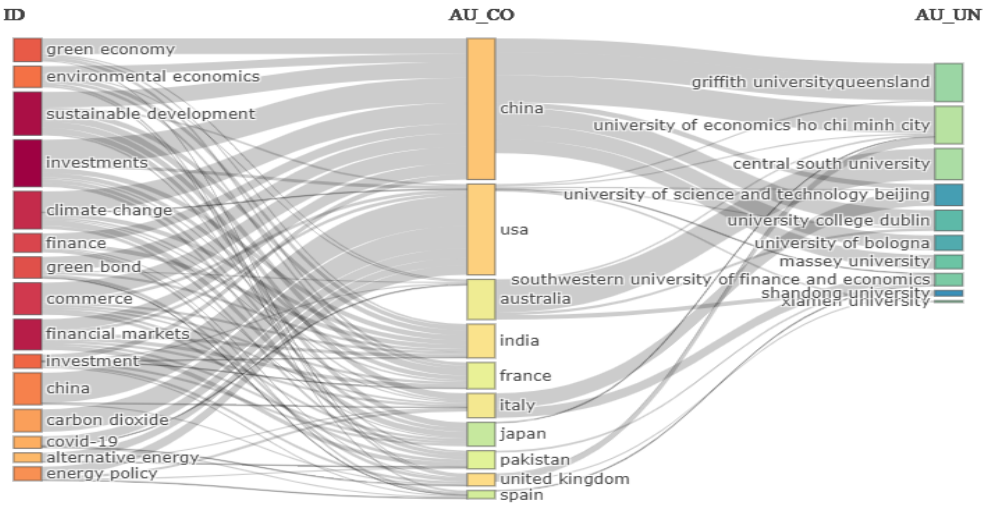


**Figure 6 Three-field plot of 'green bonds' literature**
Source: Own processing based on Biblioshiny tool using RStudio.

Also, the figure indicates that authors' affiliations with the USA, Australia, India, France, Italy, Japan, Pakistan, United Kingdom and the USA are significantly contributing to green bond publications.

### 3.2 Networks of publications in green bonds literature

To identify the main journals involved in publishing green bond literature, this paper uses Bradford's Law pattern formulation. Figure 7, as per Bradford's Law, ranks the journals based on the number of articles published on green bonds in these journals. Finance Research Letters with 21 articles is the most relevant source with the most

number of research publications in the green bonds field. This top position is followed by Sustainability (18 articles), Journal of Sustainable Finance & Investment (17 articles), and Journal of Cleaner Production (16 articles).

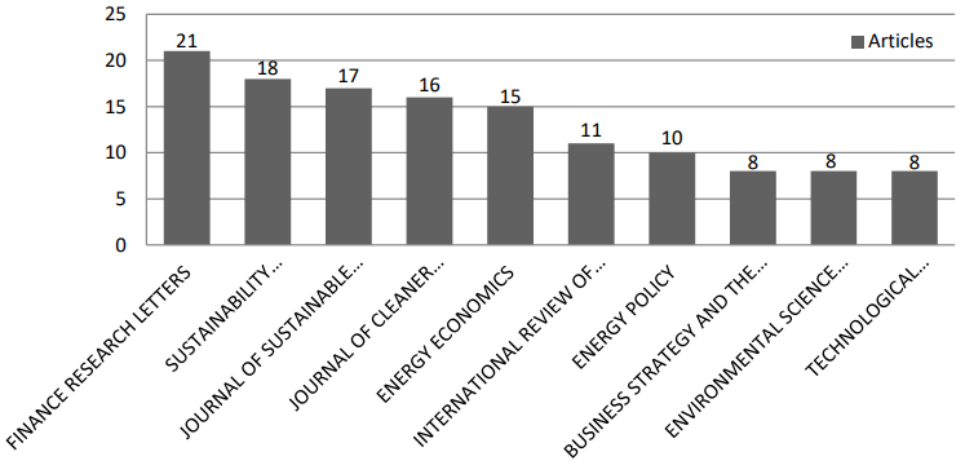


**Figure 7 Journals ranking as per Bradford's Law**
Source: Own processing based on Biblioshiny tool using RStudio.

Table 3 highlights the division of the top 10 journals on green bond literature into different zones as per Bradford's Law.

**Table 3 Journals ranking as per Bradford's Law**

| Top journals | Rank | Freq | cumFreq | Zone |
|---|---|---|---|---|
| Finance Research Letters | 1 | 21 | 21 | 1 |
| Sustainability (Switzerland) | 2 | 18 | 39 | 1 |
| Journal of Sustainable Finance and Investment | 3 | 17 | 56 | 1 |
| Journal of Cleaner Production | 4 | 16 | 72 | 1 |
| Energy Economics | 5 | 15 | 87 | 1 |
| International Review of Financial Analysis | 6 | 11 | 98 | 1 |
| Energy Policy | 7 | 10 | 108 | 1 |
| Business Strategy and the Environment | 8 | 8 | 116 | 1 |
| Environmental Science and Pollution Research | 9 | 8 | 124 | 2 |
| Technological Forecasting and Social Change | 10 | 8 | 132 | 2 |

Source: Own processing based on Biblioshiny tool using RStudio.

Zone 1 is the 'core zone' which signifies the main sources for publishing the green bonds research articles. Zone 1 is also referred to as the nuclear zone which denotes the journals with important publications. It shows that a total of 8 journals come under Zone 1 out of 154 journals, whereas the remaining journals belong to Zone 2 and 3. These top 10 journals are considered the main sources for publications in the field of green bonds. The above statistics revealed that, out of 342 articles related to green bonds, 132 are published in the top 10 journals.

Moreover, looking at the top journals as per source impact, Table 4 reports the ranking of the journals according to h-index, total citations (TC), net production (NP), and starting year of publication (PY-start). Analysis in Table 4 highlights that Finance Research Letters is again at the top position concerning the journal's h-index, whereas, Energy Economics is a leading journal concerning the total number of citations. Similarly, in net production (NP), Finance Research Letters is in a leading position with net production of 16.

**Table 4 Top journals as per source impact**

| Top 10 Journals | h-index | TC | NP | PY-start |
|---|---|---|---|---|
| Finance Research Letters | 10 | 422 | 16 | 2018 |
| Energy Economics | 9 | 445 | 12 | 2018 |
| Journal of Sustainable Finance and Investment | 9 | 357 | 15 | 2016 |
| Journal of Cleaner Production | 8 | 416 | 13 | 2018 |
| Sustainability (Switzerland) | 8 | 253 | 12 | 2019 |
| Energy Policy | 7 | 240 | 9 | 2016 |
| Technological Forecasting and Social Change | 6 | 233 | 8 | 2020 |
| Business Strategy and the Environment | 4 | 82 | 5 | 2019 |
| Environmental Science and Pollution Research | 4 | 31 | 6 | 2021 |
| International Review of Financial Analysis | 4 | 80 | 8 | 2020 |

Source: Own processing based on Biblioshiny tool using RStudio.

Furthermore, a bibliometric mapping analysis of top journals regarding green bond literature is performed. A bibliometric mapping provides a means to visualize the academic output as publications and citation information for parameters of a particular field. In mapping analysis, the size of the node is important to explain the number of publications in the journal. Bibliometric Figure 8 shows that the size of a node of Finance Research Letters is larger, indicating that this journal has published the most number of articles on green bonds as compared to other journals.

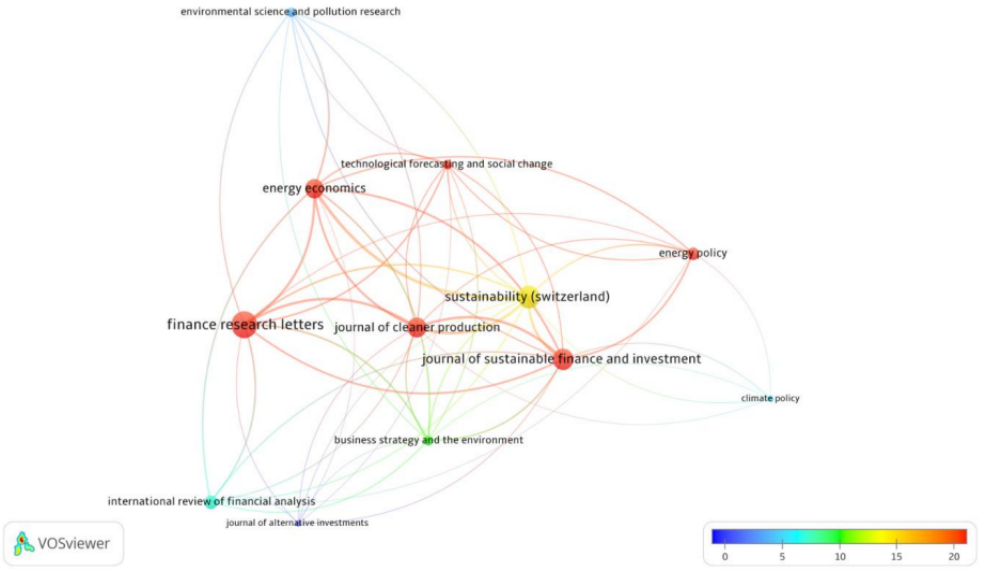


**Figure 8 Bibliometric mapping analysis of top journals**
Source: Own processing based on VOSviewer.

Figure 9 highlights the publication growth tendency of top journals regarding green bond literature over the years. A sharp growth trend of publications is observed in Finance Research Letters with the first article published in 2018 to a total of 21 publications. Similarly, a fast publication growth trend is also observed in other journals such as Sustainability (Switzerland), with the first article published in 2019 to a total of 18, Journal of Sustainable Finance and Investment with the first article published in 2016 to a total of 17, and Journal of Cleaner Production with the first article published in 2018 to a total of 16 An interesting observation of significant publications growth over a comparatively short period concentrating on green bond literature is seen in the International Review of Financial Analysis, with the first article published in 2020 to a total of 11 articles recently. Lastly, a relatively slow but steady rise in publication trend is observed in Energy Policy, with the first article published in 2016 to a total of 10 articles. In conclusion, there is a mixed trend of articles published on green bonds across the journals.

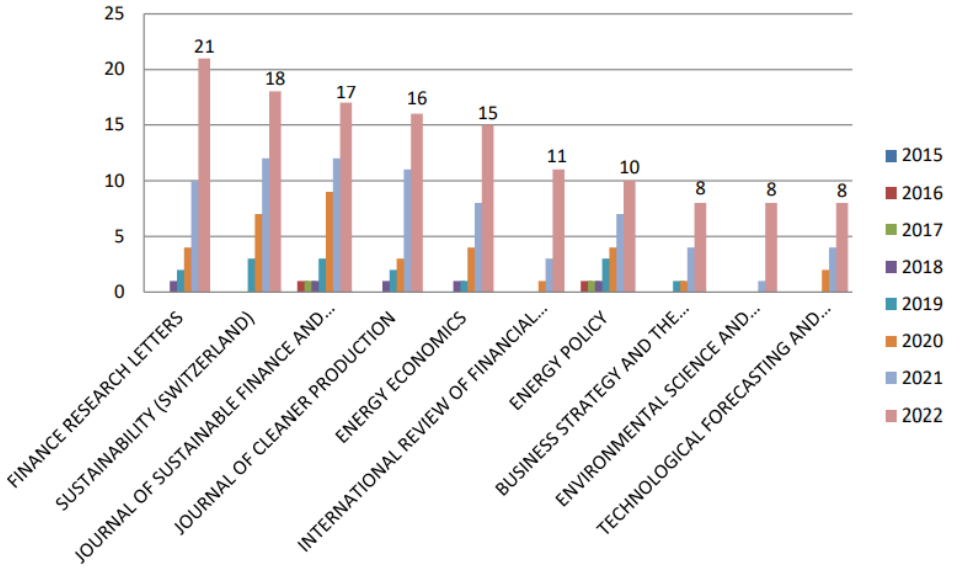


**Figure 9 Growth trends of top journals in publishing green bonds literature**
Source: Own processing based on Biblioshiny tool using RStudio.

Overall, Finance Research Letters is an impactful journal regarding green bonds literature, in terms of the number of publications and h-index. Publication details regarding green bonds in this source title include the eminent researchers of recent and well-known research articles, articles' title and publication year, are depicted in Table 5.

**Table 5 Recent publications in Finance Research Letters on green bonds**

| Authors Name | Paper Title | Year |
|---|---|---|
| Naeem | 'Asymmetric relationship between green bonds and commodities: Evidence from extreme quantile approach' | 2021 |
| Nguyen | 'Time-frequency comovement among green bonds, stocks, commodities, clean energy, and conventional bonds' | 2021 |
| Hyun | 'Pricing of Green Labeling: A comparison of labeled and unlabeled green bonds' | 2021 |
| Pham | 'How does investor attention influence the green bond market?' | 2020 |
| Tu | 'Investigating solutions for the development of a green bond market: Evidence from analytic hierarchy process' | 2020 |

| | | |
|---|---|---|
| Broadstock | 'Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade' | 2019 |
| Wulandari | 'The impact of liquidity risk on the yield spread of green bonds' | 2019 |

Source: Own processing based on Biblioshiny tool using RStudio.

Broad topics of green bonds are covered in Finance Research Letters. Nguyen et al. (2021) investigated the association among conventional bonds, commodities, clean energy and green bond markets. They discovered that the green bond market has a negative relationship with both the commodity and equity markets, where the price swings in these markets are sheltered by green bonds. To gain the benefits of diversification, it is therefore recommended to combine green bonds with commodity and equity markets in investment settings. Additionally, the diversification advantage of green bonds is demonstrated across all investment prospects, but over the long term, it is evidenced that the hedging ability of green bonds has declined.

Hyun et al. (2021) empirically investigated the difference in price between labeled and unlabeled green bonds. They found that even though unlabeled and labeled green bonds have identical properties, unlabeled green bonds have higher yields. It demonstrates that in the market for green bonds, having a green label matters. The green labels, independent evaluation, and public perception serve as a measure of their environmental risk. Investors will pay more for a green label because they believe it reduces asymmetric information on greenness and so reduces environmental risk. When compared to identical green bonds, issuers who carry a green label will benefit from cheaper financing costs.

In another paper by Naeem et al. (2021), it is found that there is an asymmetric relationship between green bonds and a group of commodities comprising agriculture, metals and energy. A unique cross-quantilogram method was adopted, where they observed the diversification and hedging advantage of the green bond, hence recommending combining green bonds with agriculture, metal and energy commodities in a portfolio setting. Also, they discovered that green bonds provided the best protection against market volatility for industrial metals, agricultural commodities and natural gas in the long run.

Meanwhile, Tu et al. (2020) looked into potential solutions for green bond market growth in Vietnam which recently attempted to establish itself as a successful investment mechanism for financing low-carbon projects. The finding indicates that an effective regulatory structure for the operations of green bonds, the State Bank of Vietnam's monetary policies, and the official green bonds interest rates are significant accelerators the nation can use to expand its green bond market.

Pham & Huynh (2020) investigated the relationship between green bond returns, volatility and investors' attention. The findings reported that investor attention can affect the volatility and returns of green bonds, although this relationship varies over time. This finding highlights the significance of providing the right information to investors and paying attention to them, especially in the rapidly expanding green bond market. Likewise, Broadstock & Cheng (2019) reported that the relationship between green bonds and black bonds is sensitive to variations in uncertainty in economic policy, financial market volatility, oil prices, everyday economic activity and specially crafted metrics of positive and negative news-based attitudes about green bonds.

Wulandari et al. (2018) conducted a study to examine the effect of liquidity risk on green bonds' yield spreads, which is measured by 'LOT' and the 'bid-ask spread'. It is revealed that green bond liquidity is more compared to conventional bonds, where both measures of liquidity have a positive relationship with the green bond's yield spreads. Additionally, it is also discovered that the influence of LOT variable diminishes over time, signifying that the influence of liquidity risk on green bonds' yield spreads has become less relevant in recent years. This last finding might indicate that green bonds are becoming a more mature financial asset.

### 3.3 Authorship in green bonds literature

Lotka's law was used to measure the distribution of authors' production based on the research papers published on green bonds through the Biblioshiny tool. The measurement is valid for quantifying productivity globally, not only in academic research but also for measuring productivity in other disciplines as well (Rowlands, 2005). Table 6 describes the result of the authors' productivity.

**Table 6 Author's productivity through Lotka's law**

| Documents published | No. of Authors | Proportion of Authors |
|---|---|---|
| 1 | 646 | 0.837 |
| 2 | 85 | 0.11 |
| 3 | 20 | 0.026 |
| 4 | 12 | 0.016 |
| 5 | 5 | 0.006 |
| 6 | 1 | 0.001 |
| 7 | 2 | 0.003 |
| 13 | 1 | 0.001 |
| Total | 772 | |

Source: Own processing based on Biblioshiny tool using RStudio.

It can be seen that out of a total of 772 authors, 646 authors (83.7%) have published only one research paper on green bonds, 85 authors (11%) have published two research papers and 20 authors (2.6%) have published three research papers.

Furthermore, authors' h-index and citation examination were carried out to determine the most prominent and impactful authors. The research productivity of each of the 772 authors mentioned in this study was evaluated by comparing their research papers and the citations they received to get their unique h-index ranking using Biblioshiny interface. An author-level index/measure named h-index aims to measure the researchers' publications production as well as citations' impact (Hirsch, 2005). The h-index is calculated based on the gathering of research papers most cited by the scholars as well as the number of citations they have earned in other journals (Aria & Cuccurullo, 2017). The greater the h-index, the more significant the author's research is (Niñerola et al., 2019). The most prominent 20 researchers based on h-index in the field of green bonds with at least two research papers published are presented in Table 7. It depicts that Naeem, Pham, and Shahzad having an h-index of 9, 5 and 4 respectively are the top three impactful researchers in the field of green bonds. However, concerning total citations, Reboredo, Naeem and Pham are the most influential authors.

**Table 7 Top 20 Authors' Impact on green bonds literature**

| Authors | h-index | TC | NP | PY-start |
|---|---|---|---|---|
| Naeem | 9 | 284 | 12 | 2021 |
| Pham | 5 | 195 | 7 | 2016 |
| Shahzad | 4 | 112 | 4 | 2021 |
| Tiwari | 4 | 100 | 4 | 2021 |
| Vo | 4 | 128 | 5 | 2020 |
| Bourie | 3 | 112 | 4 | 2020 |
| Keeley | 3 | 143 | 3 | 2019 |
| Lee | 3 | 150 | 5 | 2021 |
| Li | 3 | 48 | 5 | 2021 |
| Managi | 3 | 144 | 4 | 2019 |
| Mensi | 3 | 27 | 3 | 2021 |
| Park | 3 | 55 | 3 | 2020 |
| Rasoulinezhad | 3 | 60 | 4 | 2020 |
| Reboredo | 3 | 319 | 4 | 2018 |
| Taghizadeh-Hesary | 3 | 59 | 5 | 2021 |

| | | | | |
|---|---|---|---|---|
| Tolliver | 3 | 143 | 3 | 2019 |
| Ugolini | 3 | 165 | 3 | 2020 |
| Wang | 3 | 31 | 3 | 2021 |
| Zhang | 3 | 148 | 3 | 2020 |
| Abakah | 2 | 67 | 2 | 2021 |

Source: Own processing based on Biblioshiny tool using RStudio.

These authors provide insightful research on green bond. Naeem et al. (2021) discovered that there is a strong dependence between green bond and energy markets. It is observed that there is a negative dependency between energy commodities like coal, heating oil, gasoline, crude oil and the green bond market and a positive dependency between natural gas and green bond.

Pham (2016) investigated the volatility of the green bond market and found that the 'labeled segment' of green bond market has greater volatility as compared to the 'unlabeled segment'. The spillover effect in the green bond market is evidenced due to conventional bond market shocks. Pham (2021) also observed the relationship between green bonds and green equity market; this market connection is strong and large in extreme market circumstances.

Tiwari et al. (2021) investigated the relationship between renewable energy, carbon prices and green bond stocks in terms of return patterns, but this association is varied over time as well as dependent on the happening of any economic event. In addition, it is observed that out of all stocks, clean energy is considered the main transmitter of shocks.

However, merely depending on the score of researchers' h-index may lead to the elimination of a few of the most significant scholars who have fewer articles yet receive a lot of in-depth citations within the field. A lower h-index score may result from scholars who produce fewer articles but get higher citations since the h-index takes into account both the productivity of scholars as well as the number of citations they get. Hence, citation analysis was carried out to identify the most pertinent scholars and research articles. The most popular technique for determining the impact of a researcher, paper, or journal is citation analysis as it makes it simple to locate important pieces of research in any discipline (Zupic & Čater, 2015). Therefore, to visualize the most influential authors, mapping analysis is performed based on authors' citations. Figure 10 highlights the mapping analysis of the most influential authors based on their citations in the field of green bonds.

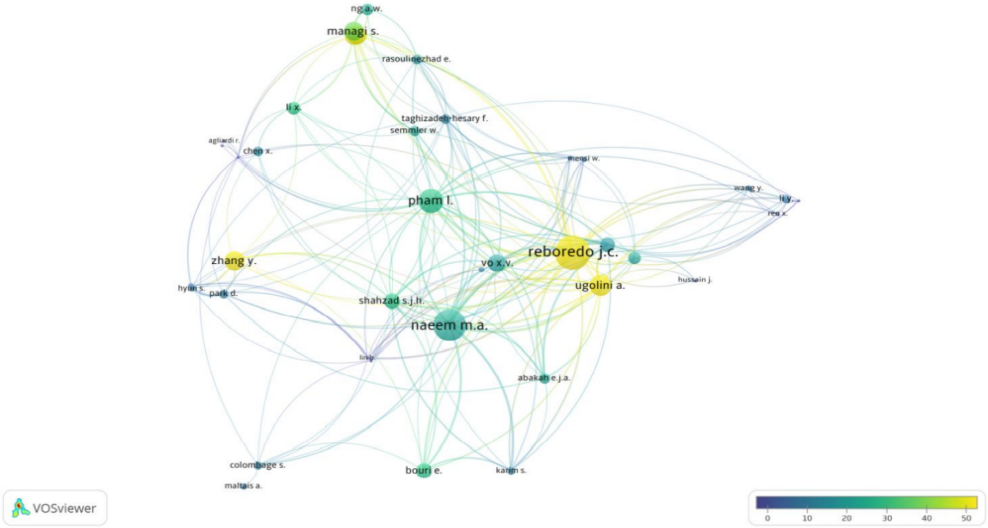


**Figure 10 Mapping analyses of the most influential authors**
Source: Own processing based on VOSviewer.

Figure 10 shows that the size of the node of Reboredo is larger, indicating that he got the most number of citations (319) regarding his research work on green bonds. Further, from citation analysis, it is observed that a total of 257 documents are cited out of 342 chosen for this paper, and 85 documents are those which are not even cited once. There are two potential explanations for this, either then various research has been of poor quality or they have been newly published, therefore have not received sufficient dissemination disclosure to be cited. The majority of the studies were just newly published, so it may take some time for researchers to evaluate their implications on the subject. Similarly, only 28 articles out of the total 342 have obtained at least 50 citations, making them the most impactful studies. Table 8 highlights the top 10 most cited research papers.

**Table 8 Top 10 most cited research papers on green bonds (Scopus)**

| Authors | Year | Journal Name | Paper Title | TC | TC-PY |
|---|---|---|---|---|---|
| Zerbib | 2019 | Journal of Banking & Finance | 'The effect of pro-environmental preferences on bond price: evidence from green bonds' | 206 | 51.50 |
| Reboredo | 2018 | Energy Economics | 'Green bonds and financial markets; co-movement, | 154 | 30.80 |

| | | | | | |
|---|---|---|---|---|---|
| | | | diversification and spillover effects' | | |
| Tang & Zhang | 2020 | Journal of Corporate Finance | 'Does shareholders benefit from green bonds?' | 139 | 46.33 |
| Flammer | 2021 | Journal of Financial Economics | 'Corporate green bonds' | 107 | 53.50 |
| Gianfrate | 2019 | Journal of Cleaner Production | 'The green advantage: exploring the convenience of green bonds' | 106 | 26.50 |
| Hachenberg | 2018 | Journal of Asset Management | 'Are green bonds priced differently from conventional bonds?' | 97 | 19.40 |
| Reboredo | 2020 | Economic Modelling | 'Price connectedness between green bonds and financial markets' | 95 | 31.67 |
| Bachelet | 2019 | Sustainability | 'The green bond premium puzzle: the role of issuer characteristics and third party verification' | 90 | 22.50 |
| Banga | 2019 | Journal of Sustainable Finance & Investment | 'Green bond market and potential: a potential source of climate finance for developing countries' | 85 | 21.25 |
| Wulandari | 2018 | Finance Research Letters | 'The impact of liquidity risk on the yield spread of green bonds' | 85 | 17.00 |

Source: Own processing based on Biblioshiny tool using RStudio.

It can be seen from Table 8 that the research paper of Zerbib (2019) with 206 citations is a top-cited article, followed by Reboredo (2018) with 154 citations and Tang & Zhang (2020) with 139 citations. It should be noted that Reboredo ranked first in the competition for the author with the most citations in total whereas Zerbib ranked number 1 regarding single paper with the most citations.

Moreover, to visualize the most influential authors with the single most cited documents; mapping analysis was carried out by using the VOSviewer. Figure 11 highlights the mapping analysis of authors with the single most cited documents. It shows that the size of the node of Zerbib is larger, indicating that his single research paper receives the most number of citations.

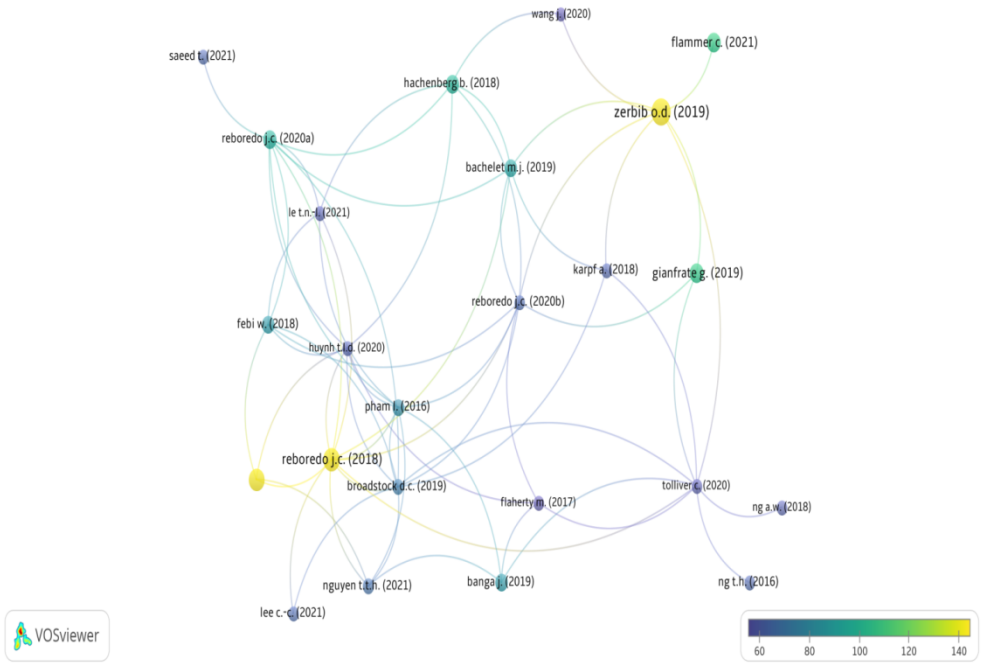


**Figure 11 Mapping analysis of authors with the single most cited document**
Source: Own processing based on VOSviewer.

These studies are interesting. Zerbib (2019) conducted a study that looked into how pro-environmental investor preferences affected the prices of conventional and green bonds. It discovered the yield on green bonds is lower as compared to conventional bonds with an average small negative premium of around 2 basis points. The primary cause of this negative premium is investors' pro-environmental preferences; however, the influence of these preferences on bond prices is low.
Reboredo (2018) tried to investigate the co-movement between financial and green bond markets and concluded that markets of treasury and corporate bonds are paired with the market of green bonds. It was seen that the advantages of diversification from green bonds are minimal for investors in markets of treasury and corporate bonds but substantial for those in the energy and stock market. Moreover, it is demonstrated that there is a significant price spillover effect of treasury and

corporate market on the prices of green bonds, however, massive fluctuations in prices of energy and stock markets have little impact on the prices of green bonds.
Reboredo & Ugolini (2020) investigated the connection of financial markets with the green bond market by applying the VAR technique that accounts for both direct as well as indirect market-to-market transmission of financial instability. The results of the study revealed that the currency market as well as the fixed-income market is tightly correlated with the market of green bonds. Further, it is found that the green bonds market receives huge price spillover through both markets and transfers a small contrary effect. However, the weak connection of the green bonds market with stock the market, the energy market and corporate bonds was observed. One of the research articles by Tang & Zhang (2020) on green bonds also has a good citation score. In this paper, they investigated that stock markets react positively to green bond issuance; hence shareholders can get benefit from green bond issuance. Similarly, Flammer (2021) found that the stock market responds positively to the issuance of corporate green bonds.

### 3.4 Determinants and Trends in green bonds research

Keywords offer a superior overview and understanding of an article's main ideas; therefore they are seen to reflect the heart of published articles (Xie et al., 2020). According to Zhang et al. (2015), keywords plus and author's keywords are typically regarded as an analysis unit in the bibliometric study, which demonstrates the article's content. Keywords plus is comparatively less detailed. Consequently, the authors' keywords were used as an analysis unit for this study for a more thorough study.
Words cloud analysis was performed by using the Biblioshiny tool to find out the most frequent words used in green bonds literature. Figure 12 highlights the words' cloud analysis of this study.


**Figure 12 Words' cloud**
Source: Own processing based on Biblioshiny tool using RStudio.

Additionally, Table 9 reports the results of recurrent authors' keyword. From the analysis, it can be seen that the word 'green bonds' is used commonly with a frequency of 172 in publications. Overall, the following author's keywords recurrences are observed: green bond (56), green finance (41), climate change (24), and sustainable finance (20), to name a few. The word Covid-19 in green bonds literature indicates the studies on green bonds during a global Covid-19 pandemic. The literature on green bonds is mostly related to climate change, environmental sustainability, energy and sustainable finance aspects. All these authors' keywords analysis concludes that different stakeholders can use green bonds literature to address the issue of climate change along with the business and shareholders' benefits.

**Table 9 Most recurrent authors' keywords**

| Terms | Frequency |
|---|---|
| green bonds | 172 |
| green bond | 56 |
| green finance | 41 |
| climate change | 24 |
| sustainable finance | 20 |
| climate finance | 19 |
| renewable energy | 16 |
| sustainable development | 16 |

| | |
|---|---|
| covid-19 | 15 |
| sustainability | 13 |
| energy efficiency | 12 |

Source: Own processing based on Biblioshiny tool using RStudio.

Further, to highlight the pattern of authors' keywords in terms of their use over the years, words dynamics analysis was performed. According to Figure 13 the keyword 'green bonds' progressed the most rapidly of all the keywords used in numerous pieces of research.

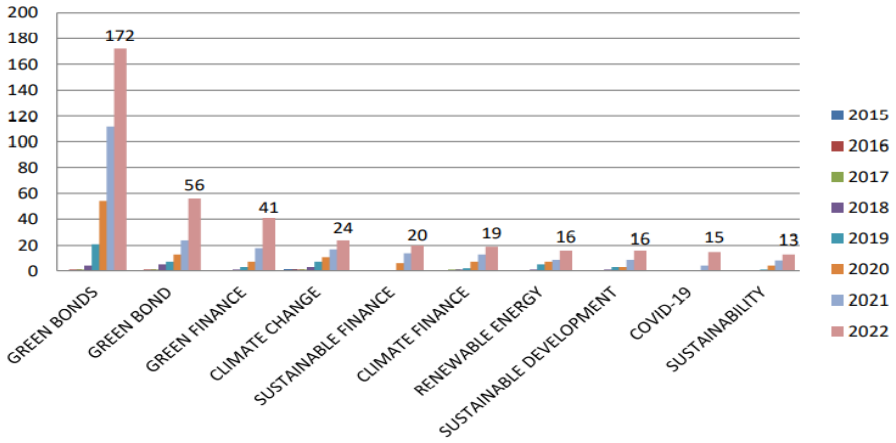


**Figure 13 Authors' keywords trend (annual)**
Source: Own processing based on Biblioshiny tool using RStudio.

Moreover, according to Su et al. (2019), analyzing the co-occurrence of terms is indeed an effective technique to show the arrangement of scientific knowledge, revealing research hotspots and trends. Figure 14 highlights the network analysis of authors' keyword co-occurrence using the VOSviewer. To recognize the prominent themes, keywords occurrence frequency is captured. The minimum threshold of the keyword occurrence is set to 4 times. With this criterion, 44 authors' keywords out of 967 were eligible for co-occurrence analysis.

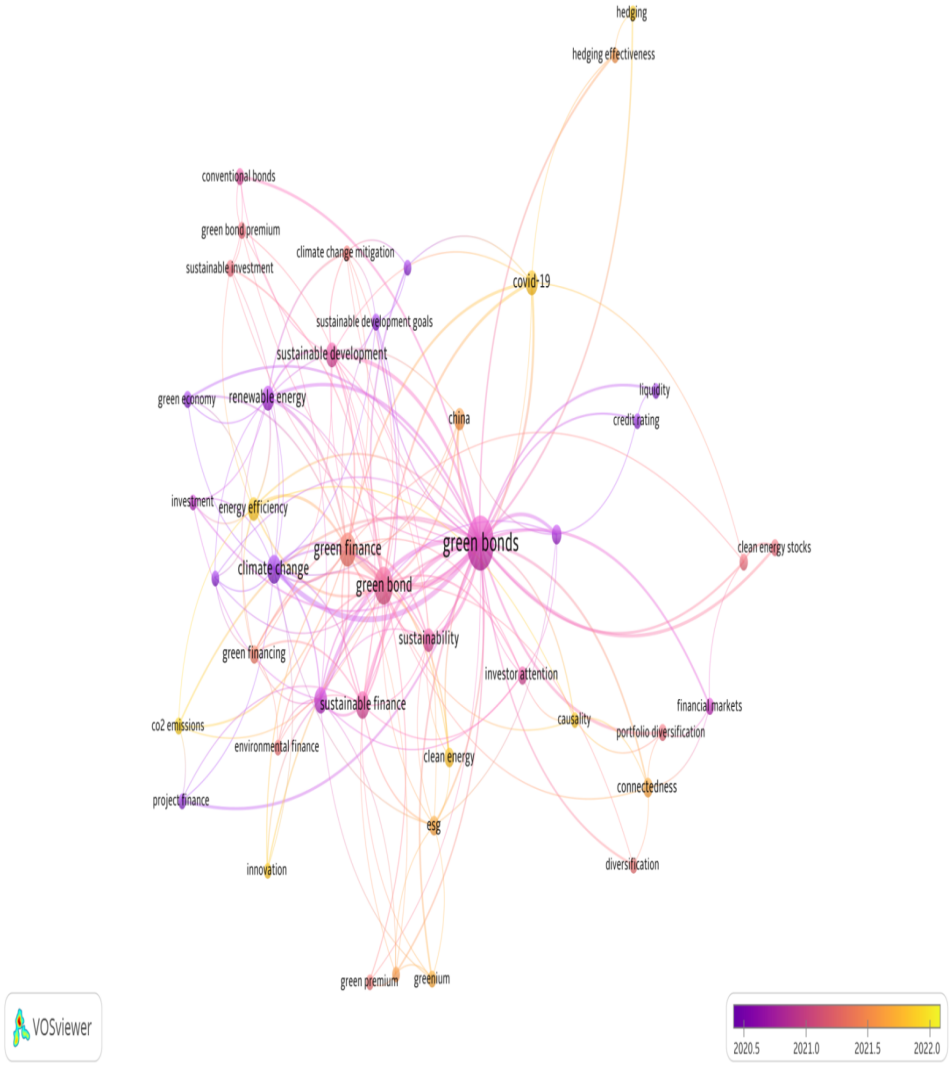


**Figure 14 Authors' keywords co-occurrence analysis**
Source: Own processing based on VOSviewer.

Based on network analysis, it can be seen that 'green bonds' is one of the most leading phrases to elaborate on this occurrence. Co-occurrence analysis showed that the word 'green bonds' occurred with other authors' keywords such as sustainable investment, sustainability, green financing, sustainable finance, financial market, clean energy markets, and energy efficiency. This confirms the consensus of the 'green bonds' concept over its wider reaches and dimensions. Moreover, Figure 13 also reveals that a few keywords have attracted more attention such as green finance, which indicates the concern that how green bonds are used for financing green projects (Park, 2018). Similarly, climate change is also a prominent keyword that occurred with green bonds showing that green bonds are used to mitigate the risk raised by climate change (Banga, 2019). China is also the main actor in green finance and hence a focus for research on green bonds (Wang et al., 2020). Covid-19 the recent concept under consideration has occurred with green bonds to identify whether an investment in green bonds is a safe-haven investment during Covid-19 (Arif et al., 2022). Likewise, green bonds are important financial tools for sustainable development (Maltais & Nykvist, 2020). Renewable energy and energy efficiency projects are also closely occurred to green bonds because proceeding from these bonds is used for these projects (Climate Bond Initiative, 2022).

The study of keywords indicates significant data that helps to explain the basic concepts of green bonds. Green bonds have a connection to green finance, sustainable finance and development, and climate change, and must be policy-driven. The main areas of focus revolve around financial or investment issues related to climate adaptation. Thus, financial economists must contribute to the field of green bonds.

### 3.5 Geography in green bond research

An essential part of the empirical literature is the production of the countries as well as organizations concerning research publications on green bonds. Figure 15 reports the scientific production report of countries, highlighting that there are a total of 20 countries that have published at least 10 articles in the field of green bonds.

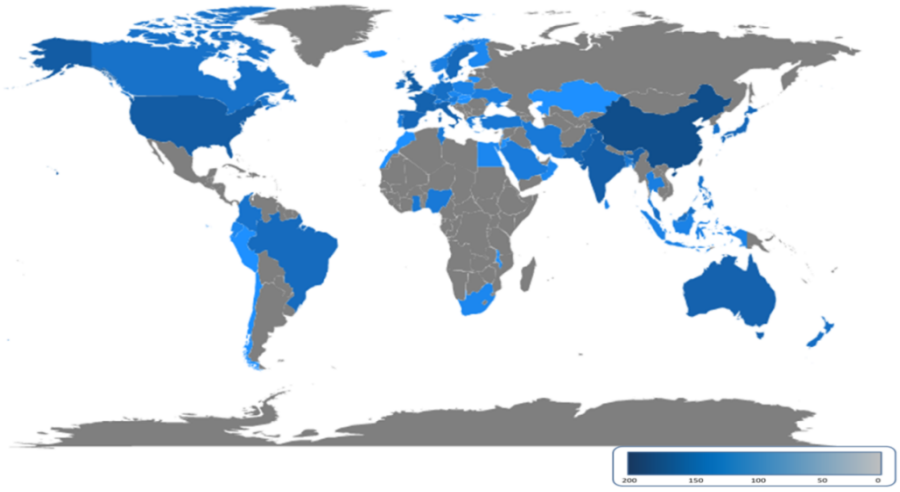


**Figure 15 Scientific productions of countries**
Source: Own processing based on Biblioshiny tool using RStudio.

Out of these countries, the top three countries are China with 212 publications followed by the USA with 64 and the UK with 59 research publications.
Besides this, Figure 16 highlights that France with 462 citations is at the top of the list among the most cited countries, followed by China with 435 and the USA with 368 citations.

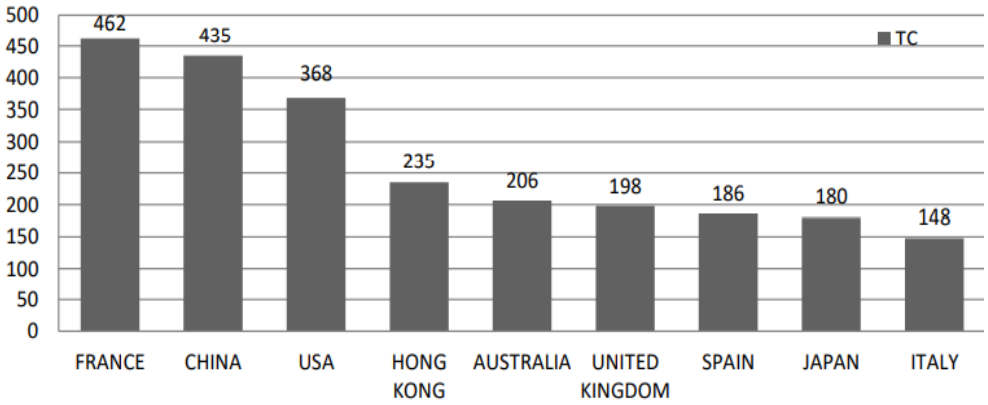


**Figure 16 Most cited countries**
Source: Own processing based on Biblioshiny tool using RStudio.

Additionally, the production of the various institutes that the scholars were affiliated with at the time of publication has been examined to detect the institutions that have the greatest impact on research into green bonds. Figure 17 shows that the three top pertinent universities with the highest number of publications on green bonds are the University of Economics Ho Chi Minh City in Vietnam (15 articles), Central South University in China (14 articles), and Griffith University Queensland in Australia (10 articles).

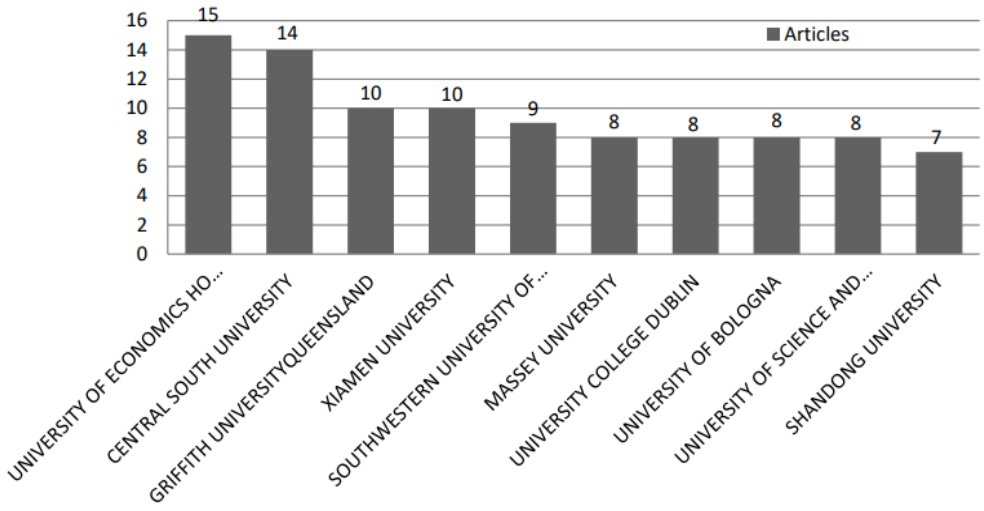


**Figure 17 Most pertinent institutions regarding publications on green bonds**
Source: Own processing based on Biblioshiny tool using RStudio.

## 4. Conclusions and future directions

The current study uses a fundamental bibliometric methodology for assessing the existing aspects and trajectory of scholarly research on the topic of green finance. The five frequently contested aspects of green bonds literature including sources, authors, geography of publications, dimensions, and particularly development are evaluated. This study identifies significant material that can assist in developing a precise understanding of this particular topic through the ranking and network analysis, as well as the visual presentation of a variety of important factors, of a sample of 342 research papers.

Bibliometric analysis on green bonds has demonstrated its considerable contribution and expanding applicability. Analysis showed that green bonds are studied in finance literature along with environmental sustainability and climate change literature such

as in finance; green bonds are studied in terms of green premium, stock market reaction and green bonds and other financial and commodities markets connectedness. Hence, the growing interest in modern literature in major finance and economics journals along with environmental sustainability and climate-related journals has provided opportunities to scholars in three ways for future advancement. Firstly, it is crucial to analyze green bonds from a financial point of view and employ financial methods. The following possible topics for future research are:

- Financial market and commodities market connectedness with sub-segments of the green bonds market;
- Difference in stock price reaction to green bond issuance concerning the industry of issuer;
- Difference in magnitude of stock reaction to green bonds issuance when comparing the issuers that belong to different countries;
- Difference in the magnitude of stock market reaction to green bonds issuance by comparing the issuers that belong to countries with different national cultures and country environmental performance;
- Green bond market performance analysis;
- Green bond supply-side analysis.

Secondly, additional research on green bonds carried out from the standpoint of developing nations would help policymakers and regulators to integrate various policy objectives and establish clear policy agenda. Researchers of developing nations would be provided maximum opportunities with evident informational benefits, so increased international cooperation among developed and developing nations is anticipated. Thirdly, it is important to note that green bond research is mostly policy driven. Fresh challenges in this area are expected to arise with the altering of the world economy and political environment.

## 5. Limitations and Implications

Despite implementing a sophisticated bibliometric methodological approach, this study has certain limitations. First of all, by manually filtering article titles, keywords, and abstracts to ensure that only relevant papers are chosen, it is indeed possible that any reference to this area in the publication's body has been missed. Secondly, because this work only attempted to evaluate the pertinent quantitative literature, using a qualitative method to evaluate these works would be encouraging for future studies. Regardless of the limitations indicated above, the information examined in this research offered a fresh and valuable understanding of expanding body of work on green bonds. The possible future suggestions recommended in this paper will give the desired and important guidelines to researchers for future research on green bonds.

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**Author Contributions**
TR is responsible for the data analysis, interpretation, and drafting of the manuscript. The other authors have provided inputs for the manuscript's content and editing.

**Disclosure statement**
The authors have not any competing financial, professional, or personal interests from other parties.

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