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Green Swan: Mapping green finance in the age of climate change

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Keywords

Green finance
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Bibliometric analysis
Literature review

Abstract

The present study is a literature review conducted by applying the bibliometric analysis technique. The researchers attempt to map the impact of green swan events and climate related risk and their implications on the sustainable development. The Scopus database was used to download the documents, which extracted 142 items from the period 2009–2022. Further, the basic information and science mapping were reported using Biblioshiny package of R and Vos viewer. The findings of the study indicated that there has been exponential growth in research of sustainable finance in the context of climate change. Moreover, China is the leading country involved in the research in this domain followed by the UK. One of the important research gaps identified from the study is that the research in this domain is concentrated in developed nations and needs to cover all developing nations.

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1. Introduction

Sustainability and climate change have drawn international attention. Many industrialised nations such as the United States and the United Kingdom, and international bodies, including the United Nations and the European Union, have released policies and initiatives to support sustainable financial development. World leaders have reached an accord on this subject, the 2015 Paris Agreement, within the United Nations Framework Convention on Climate Change. There is increasing recognition that climate change is a cause of financial (and pricing) instability since it is likely to produce physical risks linked to climatic damages and transition risks related to potentially disordered mitigation strategies (Bolton et al., 2020). The Central Banks and Supervisors Network for Greening the Financial System (NGFS) was founded out of a desire to strengthen the financial system's capacity to manage risks and mobilise money for green and low-carbon initiatives in environmentally sustainable development. However, due to the unique characteristics of climate change consequences and mitigation options, integrating climate-related risk analysis into financial stability monitoring and prudential oversight is notoriously problematic. Therefore, climate change may result in "green swan" occurrences and cause the subsequent systemic financial crisis (BIS, 2020). Climate-related disasters, commonly termed “green swan events” due to their unpredictable and catastrophic nature, present substantial physical and transition risks to the overall macroeconomic and financial landscape (Ghosh, et al., 2021).

The “black swan” idea, popularised by Nassim Nicholas Taleb, served as an influence for the “green swan” idea (2007). Three components characterize black swan events: (i) they are unusual, unforeseen events that fall outside the sphere of usual expectations; (ii) their repercussions are broad-reaching or dramatic; and (iii) they are only fully explicable after the fact. Green swans, sometimes known as “climate black swans,” have many characteristics of traditional black swans (Bolton et al., 2020). Green swans, however, vary from black swans in three ways. *First,* there is a high degree of certainty that some combination of physical and transition risks will manifest in the future, even though the effects of climate change are largely unclear (NGFS, 2019, p.4). *Second,* as per climate experts, climatic catastrophes are much more dangerous than financial crises since they may endanger humanity's existence (Ripple et al., 2019). *Third,* the severity of climate change is greater than that of black swans, because it could result in fundamentally unpredictable environmental, geopolitical, social, and economic dynamics due to complex chain reactions and catastrophic consequences linked to both physical and transition risks (Bolton et al., 2020). Keeping this critical issue in mind, companies, investors, financial institutions, governments, and other actors advocated sustainable finance and investment strategies to solve the issues.

To sum up, climate change, sustainability and sustainable finance has emerged as the newest development trend in the world of finance. Understanding the global evolution of sustainable finance

research will be crucial for both theoretical and practical reasons. In recent years, academics have increasingly focused on the study of sustainable finance and have produced many articles on the topic. However, with thousands of papers to sort through, there is a significant danger of missing fundamental issues and areas in need of further study. The focus of the present study is to review the studies conducted concerning sustainable finance/green finance in context of climate change. Hence, the present study focuses on the following research questions:

1. What are the recent trends publications in sustainable financing and climate change?
2. Who are the most influential authors and institution publishing their research in this area?
3. Which are the most globally cited documents and authors publishing their research in this area?
4. What are the most influential themes in green finance and climate change?

The rest of the paper is organized as follows: section 2 presents the research methodology adopted in the study, section 3 presents the results followed by section 4 discussion and section 5 discusses the research gaps and future research agenda.

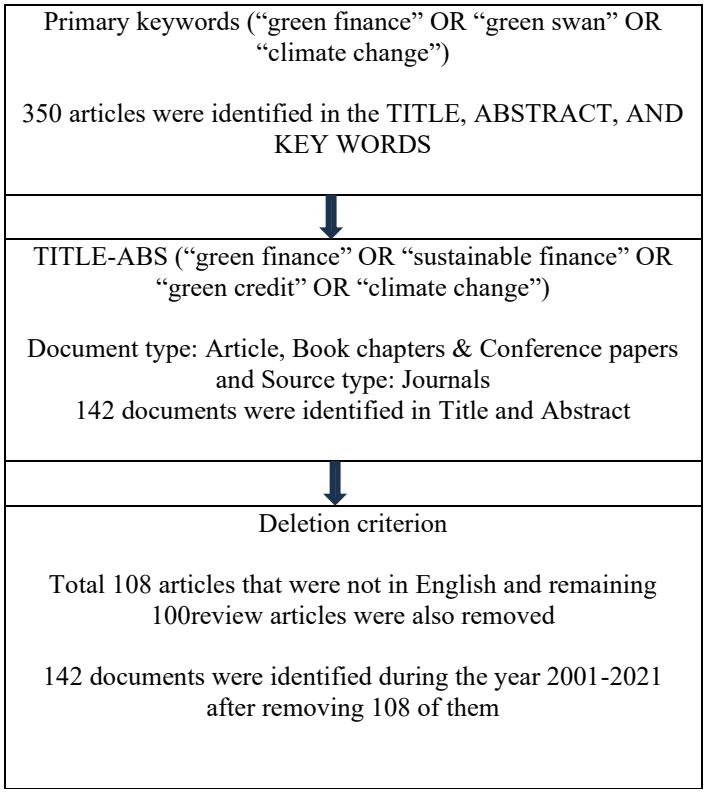
2. Methodology and data extraction

This paper employs a bibliometric analysis approach as its methodology. Pritchard (1969) used it for the first time, and it has since grown to be widely used to help quantitative analysis and literature comprehension. Bibliometric techniques employ a quantitative viewpoint to track a research area and evaluate the findings scientifically through a standardized review procedure (Chen & Xiao, 2016; Behl et al., 2019; Dave et al., 2019; Kumar et al., 2019; Mishra et al., 2017; Ramos et al., 2020; Singh et al., 2020). From the various tools used for bibliometric analysis like Bib excel (Persson et al., 2009), Biblioshiny and Vos viewer (Van Eck & Waltman, 2010), we have chosen Vos viewer for the analysis since it gives easy visualization of the citation maps (Fabregat-Aibar et al., 2019). The data was retrieved using the Scopus database during December 2022. Earlier studies have revealed that Scopus is the largest abstract and citation database for academically reputable research publications and is therefore better suited for bibliometric analysis. Similarly, the Scopus database was chosen for this study since it focuses on scientific studies from multidisciplinary fields like social sciences, management, finance, and environmental sciences giving better coverage of related papers (Bag et al., 2018; Gao et al., 2021). Secondly, Scopus has citation analysis tools that allow for tracking citation trends and impact. This was a crucial factor in identifying influential works and key developments in the field. Thirdly, it also includes significant proportion of peer-reviewed, high-quality journals, ensuring that the literature reviewed is credible and well regarded. While we acknowledge the value of other databases like Web of Science and Google Scholar, we chose Scopus due to its coverage and usability for this specific research. Web of Science has similar functionality and could have been chosen; however, the results from Scopus were sufficiently broad and relevant to our needs. As for Google Scholar, while it provides a vast collection of academic resources, it includes non-peer-reviewed material, making it less suitable for the structured and high-quality review we aimed to achieve.

Due to the lack of a conceptual definition for "green finance," we focus on three keywords: "green finance," "climate change," and “green swan”. To improve the coverage of pertinent literature, we additionally included a variety of terms with slight modifications, such as "green financing," "climate financing," "carbon financing," and "green investment. The articles in consideration spanned the years 2009 to 2022 (Table 1). The sample characteristics has been presented in table 1. The search key phrase used first was TITLE-ABS-KEY ("green finance" OR "green swan" OR "climate change"), which yielded a total of 350 articles. TITLEABS ("carbon finance" OR "green credit" OR "green supply chain financing") was the second search term, which produced 142 articles. The exclusion criterion for this study included review papers, as the goal was to conduct an independent synthesis of primary research and reviews could have led to an unintentional duplication of previously synthesized work. Book chapters were also removed, due to their broad and general nature of the content. The next step in exclusion looked at conference proceedings and articles in other languages. The study included peer-reviewed which presented new empirical data, and theoretical advancements along with theses and dissertations, which offered significant contributions to the topic

The primary subject search result was assessed based on the author, source, year, document type, nation, subject area, and affiliation. The criterion used in this study for classification were cite score, total citations, h-index, and total publications. The comprehensive workflow for the addition and deletion criterion is condensed in Figure 1 overleaf.

Figure 1: Flowchart of work



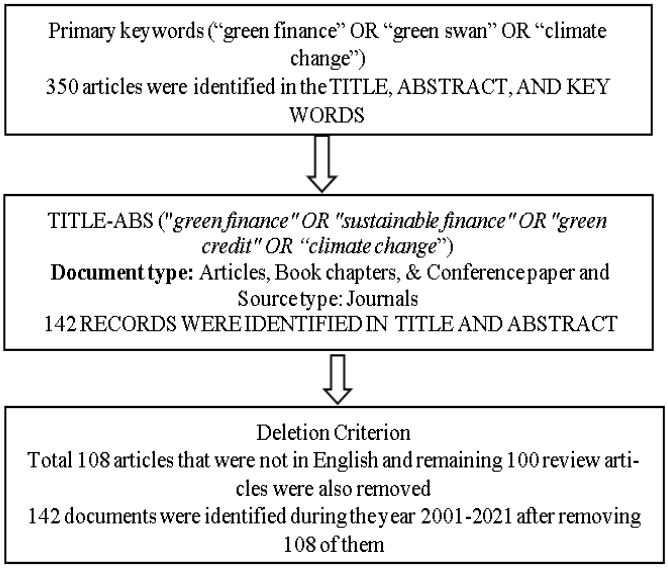


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Table 1: Sample characteristics

Timespan	2009:2022
Sources (journals, books, etc)	77
Documents	142
Annual growth rate %	38.65
Document average age	1.11
Average citations per doc	10.99
References	8523
Author's keywords (DE)	457
Authors	378
Article	142

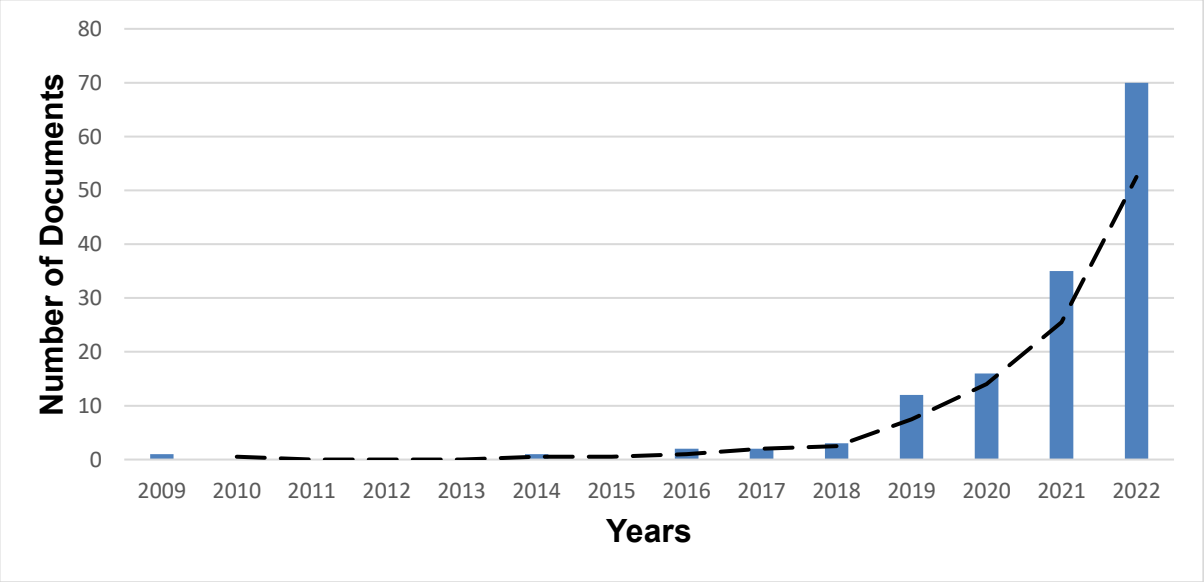
Source: Authors' own calculations

3. Results

3.1 Publication yield

Green finance has crucial significance, as evidenced by the intense debates among international institutions and governments from its inception and the vast number of publications in its name. However, the annual scientific production of articles related to our study considering green finance as a mitigation strategy for environmental concerns has resulted in 70 papers since 2009, as shown in Figure 2. A small number of publications can be seen in 2009, and none from 2010 to 2015. With the Paris Agreement in December 2015, the number of publications started rising from four in 2016 to 17 in 2020. The highest number is recorded in the year 2022. The reason for such exponential rise can be increased awareness to green financing programmes and growing global awareness to climate change and mitigation strategies, increased pressure on businesses to adopt the sustainable practices and increased investor demand for sustainable investment avenues.

Figure 2: Annual scientific production



Source: Authors' compilation

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3.2 Journal distribution

The findings indicate the leading 10 prolific journals who have published more than four relevant papers in our sample (Table 1). Whilst finance a fundamental part of green finance, the key publications turn out to be those who specialize in climate change and environmental issues. None of the journals relate to the finance domain. *Journal of Sustainable Finance and Investment* stands at the highest position with fourteen articles in this time frame. *Sustainability* journal of MDPI has second position in the list of top ten journals. One prominent economics journal in this list is *Ecological Economics*, which is a specialized journal of environmental and resource economics. Green finance has struggled to capture the attention of modern economics or finance journals, given its universally understood relevance and the pressing necessity for comprehensive policy and regulation. Much work is required to elevate this swiftly evolving area inside mainstream economics and finance study, while also addressing a substantial gap in the existing literature.

There are two justifications to support our assertions here. Firstly, there has been a significant increase in green investments in recent years, evidenced by a record $859 billion in sustainable bonds by 2020, with the peak issuance of green bonds reaching $481.8 billion[2]. Secondly, the proliferation of research outputs from a variety of academics is generating heightened interest in this topic. Therefore, we are confident that significant and groundbreaking research potential exists in this subject.

Table:2 Journal distribution with highest number of articles

Sources	Articles	h-index
Journal of Sustainable Finance and Investment	14	20
Sustainability (Switzerland)	9	109
Climate Policy	8	71
Business Strategy and the Environment	5	115
Ecological Economics	5	220
Energies	5	111
Environmental Research Letters	4	142
Environmental Science and Pollution Research	4	132
Journal Of Cleaner Production	4	232
ERA Forum	3	9

Source: Authors' calculation

3.3 Citation analysis

Articles on green and sustainable financing are frequently cited. With the help of citation analysis, the rate of the quoting a specific research paper can be analysed. The quantity of citations is indicative of the prominence of this paper in the relevant study area (Waltman, 2016). In addition to this, citation

[2] Global issuance of sustainable bonds hits record in 2021 | Reuters

analysis also enables the researchers to identify an article's recognition, the growth of that recognition, and the article's desirability for that research topic (Mishra et al., 2017). The categorization of citation analysis into global and local has been highlighted by (Tandon et al., 2022) as a vital factor in conducting the evaluation or analysis. Table:3 presents the list of globally cited documents where the study where the study by Zhang (2019) is the most cited articles with 153 total citations. This article presents a summary of current advancements in green finance research and analyses the current state and future prospects in green finance. It encapsulates that green finance should be considered as an interdisciplinary research topic. Flammer (2021) has second highest number of citations at 138, which revolves around the impact of the announcement of green bond issuances on the investors. The top globally cited documents clearly indicated that researcher is working towards climate change mitigation strategies and also studying other factors which explains faster climate change.

An increase in ownership by long-term and green investors will signal their commitment towards the environment and benefit to the corporates. Subsequent to this are other most cited articles by Nawaz (2021), D'Orazio (2019), Sikora (2021) and Galaz (2018) on green finance and climate related risks, and legal and financial challenges of climate change.

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Table 3: Top 10 Globally cited documents

Article paper	Source	Author(s)	TC	TC/Year
A bibliometric analysis on green finance: Current status, development, and future directions	*Finance Research Letters*	Zhang, D. (2019)	153	38.25
Corporate green bonds	*Journal of Financial Economics*	Flammer, C. (2021)	138	69.00
Nexus between green finance and climate change mitigation in N-11 and BRICS countries: empirical estimation through difference in differences (DID) approach	*Environmental Science and Pollution Research*	Nawaz, M. (2021)	93	46.50
Fostering green investments and tackling climate-related financial risks: Which role for macro-prudential policies?	*Ecological Economics*	D'Orazio, P. (2019)	79	19.75
European Green Deal – legal and financial challenges of the climate change	*Era Forum*	Sikora, A. (2021)	68	34.00
Finance and the Earth system – Exploring the links between financial actors and non-linear changes in the climate system	*Global Environmental Change*	Galaz, V. (2018)	64	12.80
A stock-flow-fund ecological macroeconomic model	*Ecological Economics*	Dafermos, Y. (2017)	62	10.33
Green bonds for the Paris agreement and sustainable development goals	*Environment research letters*	Tolliver, C. (2019)	45	11.25
Clean energy investment and financial development as determinants of environment and sustainable economic growth: evidence from China	*Environmental Science and Pollution Research*	Zahoor, Z. (2022)	37	37.00
Analyzing the characteristics of green bond markets to facilitate green finance in the post-COVID-19 world	*Sustainability*	Taghizadeh-Hesary, F. (2021)	37	18.50

Source: Author(s) calculations
Note: TC- Total citations; TC/year- total citations per year

3.4 Keyword co-occurrence analysis

Keywords convey essential information of any article and increase its visibility. The SCOPUS database includes author keywords as well as keywords used for indexing as part of the keyword plus feature. The keyword co-occurrence analysis facilitates the researcher in the identification and analysis of the various research themes (Lee and Sou, 2010).The SCOPUS database includes author keywords as well as keywords used for indexing as part of the keyword plus feature. Keyword analysis reveals the themes that researchers believe are most significant. With the use of Vos viewer, co-occurrence analysis has helped in reporting the frequently occurring keywords throughout the papers included in the study. Table:4 reports the most frequently used keywords with *green finance* having highest frequency of 61.

Climate change, sustainable finance, and green bonds are the next top contenders throughout the literature. These are the indicators of the importance of green finance and related ways to mitigate and find solutions to the environmental issues using financial products.

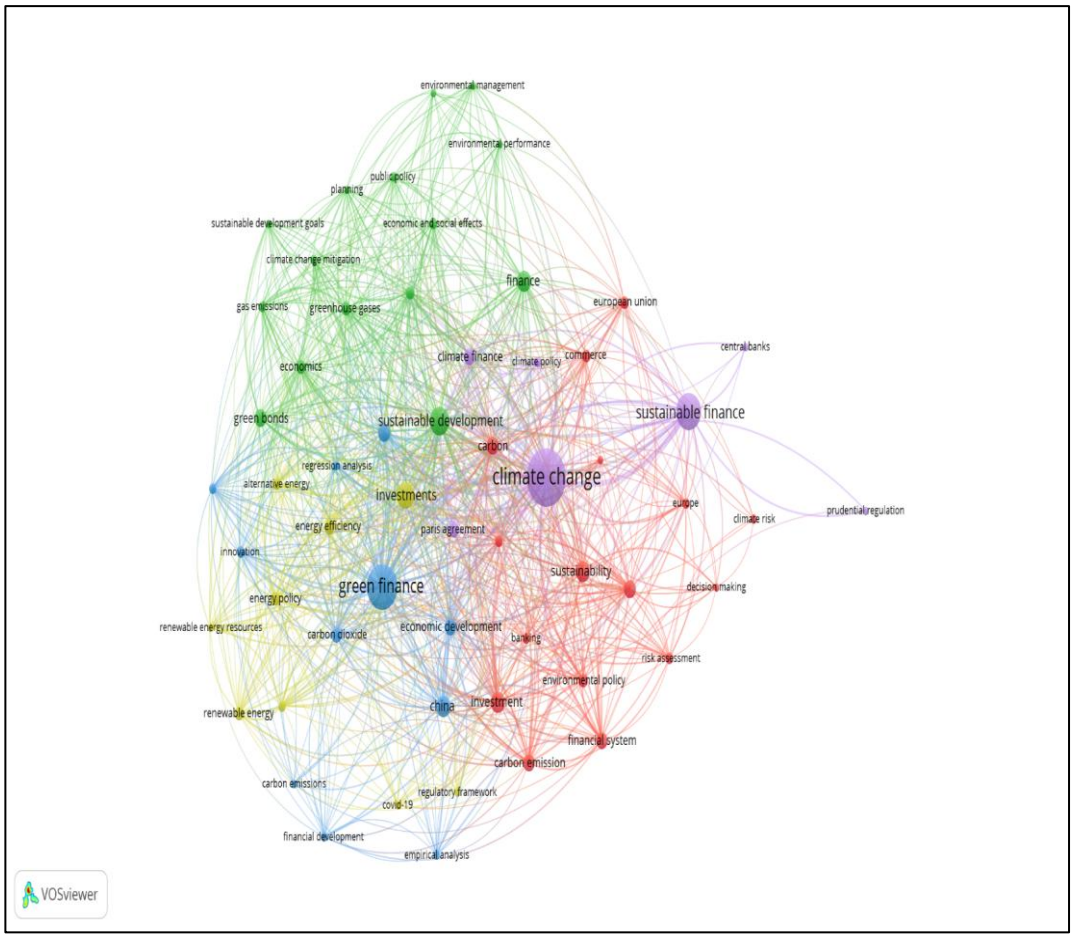
Figure 3 is a graphical representation of the keywords appearing in these articles. Together, through representation and the most prevalent keywords, several stimulating aspects are unveiled. *Sustainability* is the tenth most frequently cited keyword. It shows the concern for how sustainable finance can help in managing sustainability through green financing which can be treated as a strategy of dealing environmental issues and also being categorized as green swan events. Another pertinent keyword, *green bond*, is also closely related to green financing in Figure 3. Scholars have also shown interest in *climate risks* as *sustainable development* involves striking a balance between returns while considering the contents of *Paris agreement*. Some important keywords like *renewable energy*, *energy efficiency* and *carbon emissions* have not made it to the top ten list, but are very visible in Figure 3, suggesting a critical need to study green finance as an approach to resolve major environmental issues through financing.

Table 4: Most frequently occurring keywords

Keywords	Frequency
Green finance	61
Climate change	46
Sustainable finance	43
Green bonds	13
Climate finance	12
Paris agreement	11
China	10
Sustainable development	9
Renewable energy	8
Sustainability	8
Climate policy	5
Climate risk	5
Central banks	4
Financial development	4
Green financing	4
Prudential regulation	4
Sustainable development goals	4

Source: Authors' calculations

Figure 3: Keyword analysis



3.5 Publications by country

An examination of the number of documents published by country reveals the national origin of writers with the highest publication rates in green finance studies. Figure 4 encapsulates the data on the total published documents in various countries moving towards greener environment. It paints a clear image of the primary contributors to the recent rapid advancement of this subject, which are primarily from China, Germany, France and a few other countries. Although a huge concern for environmental sustainability through green financing is seen in India, the data shows that China is the leader and US, Sweden and India are lying in the same line. Japan and Malaysia on the other hand being developed nations also are way beyond in publications in comparison to India. This shows that India is the epicentre for further research and collaborative work in green financing.

In 2015, the Chinese government launched a green finance action plan to advance the development of ecologically friendly finance. China has achieved substantial advancements in this domain, including the establishment of green bond markets, formulation of green banking norms, and introduction of green financial goods and services. Although China is the foremost emitter of carbon dioxide globally, it has made progress in diminishing its carbon emissions through a range of projects and strategies. The five

provinces in China with the highest emissions are highly industrialised and include substantial heavy manufacturing sectors, which greatly contribute to their carbon emissions.

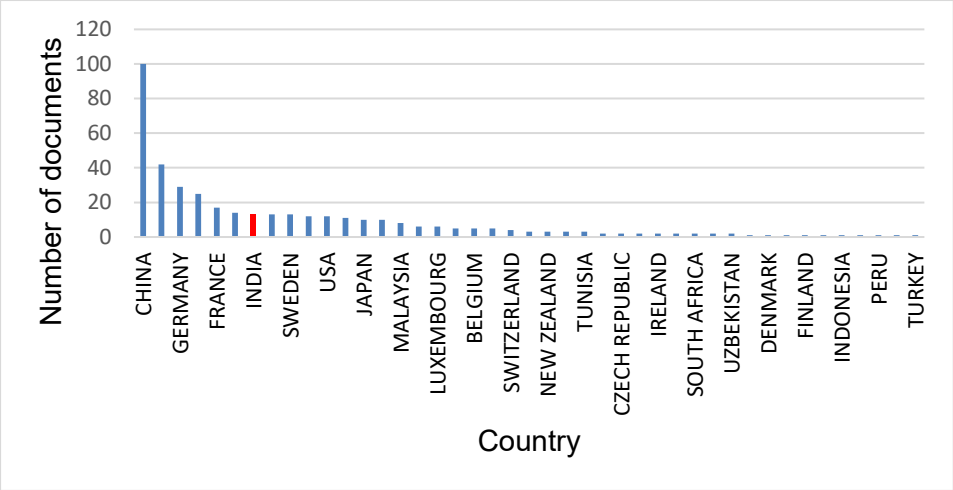
Since 2017, India has initiated measures to advance green finance, exemplified by the establishment of the Green Masala Bond Market, enabling Indian corporations to get funds in international markets for the funding of green projects. The Indian government has established a Green Finance Task Force to advance the growth of green finance. In 2019, the Japanese government initiated the Japan Green Infrastructure Fund to promote the development of low-carbon and environmentally sustainable infrastructure projects. The government has developed a framework for green finance in Japan. Such initiatives by different economies fostered the growth of green finance and climate change mitigation studies in recent years.

Table 5 presents the total citations by countries, with average article citations. China is the top with total citations of 352 followed by Germany at 121. Pakistan is in third place having 113 total citations of the published articles in this domain, while developed nations like UK, Japan, Canada and others following it. India, Philippines and Malaysia, though, are lying in the least segment with 5, 3 and 2 as total citations of the articles from the studied literature.

3.6 Collaboration by country

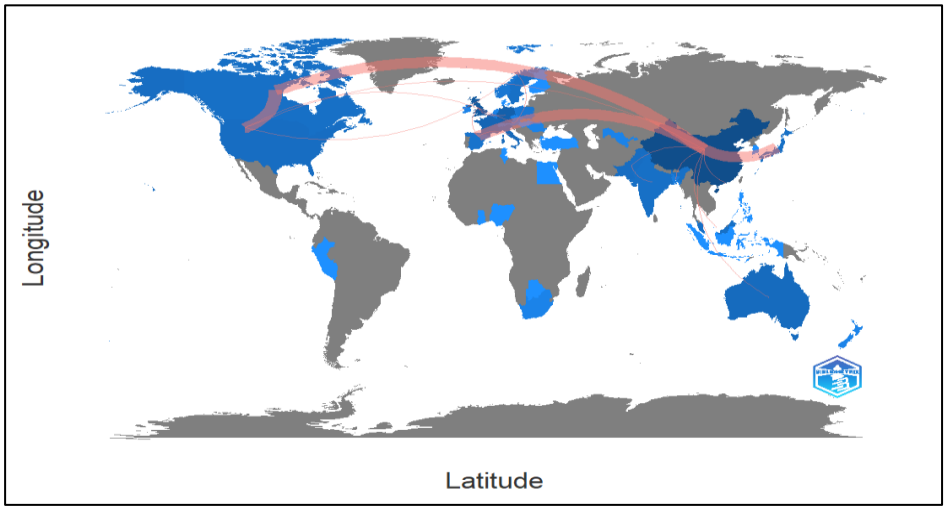
This segment discusses the collaborative effort and status of different countries. Table 6 shows China leading in research collaboration with different countries like France, Canada, Japan, and Australia. There is lesser number of research collaboration from emerging economies like India and Pakistan, but United Kingdom, France and Germany are better connected for research collaborations. Furthermore Figure:5 illustrates similar output with China leading in collaborating with others. The red lines show the connections between the countries and their thickness reveals the higher collaboration. The thickest red line connects countries like China, Canada, France and Denmark. A common linkage of collaboration is also visible with Japan with the same thickness.

Figure 4: Documents published by country



Source: R-Studio using Biblioshiny

Figure 5: Country collaboration map



Source: R-Studio using Biblioshiny

3.7 Co-citation analysis

The frequency with which two articles are cited together is referred to as co-citation (Small, 1973). The technique is commonly used in bibliometric analysis to describe the essence of a certain area of research. It is critical to create the conceptual framework of the research domain using the most significant documents. We created the co-citation network shown in Figure 6 using VOS viewer. The map shows that Zhang, Wang and Naeem are like the central node who are also focusing on add-on connecting research. The research subject has many papers to its credit and hence the map shows different coloured nodes and combined citations. However, the nodes are not well connected with each other due to

difference in the central theme. Three clusters are formed, showing a relative "clustering" of joint citations around individual topics.

Figure 6: Co-citation network map

3.8 Cluster Analysis

3.8.1 Cluster 1: Green financing towards climate change

After the thorough review of the articles given in cluster-1, the theme of cluster-1 is conceptualized as "*Green financing towards climate change*". Nawaz et al. (2021) investigates the factors that will affect how the BRICS and N-11 countries will implement their respective climate change mitigation plans. In order to encourage the decarbonisation of bank balance sheets and align finance with sustainable growth and development goals, the study by D'Orazion and Popoyan (2019) proposes a critical examination of both established and new prudential methods. The top 10 articles in cluster-1 ranked as per page rank are presented in below Table 6. By going through the documents, it is clear that articles in the cluster are focusing on green financing as remedial or mitigation strategy for the climate change all over the world. As green swan always talks in the positive terms, hence green financing has also benefitted the World to mitigate the climate-related risks. Lee. et al. (2024) found that green finance significantly facilitates energy transition through technological innovation and industrial restructuring, exhibiting pronounced regional disparities, particularly in non-central regions and areas with advanced green finance development. The proper operation of proposed climate-related financial instruments depends on a unified taxonomy and improved climate-related disclosure standards and thus "Green enhanced" capital requirements could be implemented in a post-pandemic financial policy framework to support a transformative financial response to climate change while boosting the system's resilience (D'Orazio, 2020).

Table 5:Top 10 publications in cluster 1- Green financing towards climate change

Sr. No	Article title	Author	Page rank
1	Nexus between green finance and climate change mitigation in N-11 and BRICS countries: empirical estimation through difference in differences (DID) approach	Nawaz et al. (2020)	0.324
2	Fostering green investments and tackling climate-related financial risks: Which role for macro-prudential policies?	D'Orazion & Popoyan (2019)	0.17
3	Finance and the Earth system – Exploring the links between financial actors and non-linear changes in the climate system.	Galaz et al. (2018)	0.119
4	Clean energy investment and financial development as determinants of environment and sustainable economic growth: evidence from China	Zahoor, Khan & Hou (2022)	0.195
5	Analyzing the characteristics of green bond markets to facilitate green finance in the post-COVID-19 world	Taghizadeh-Hesary, Yoshino & Phoumin (2021)	0.119
6	Greening development lending in the Americas: Trends and determinants	Yuan & Gallaghar (2018)	0.159
7	Towards a post-pandemic policy framework to manage climate-related financial risks and resilience	D'Orazio (2020)	0.097
8	A comparison of low carbon investment needs between China and Europe in stringent climate policy scenarios	Zhou (2019)	0.227
9	Decarbonization pathways and energy investment needs for developing Asia in line with 'well below' 2°C	Zhou (2020)	0.153
10	Environmental assessments and sustainable finance frameworks: will the EU Taxonomy change the mindset over the contribution of EIA to sustainable development?	Dusík & Bond (2022)	0.995

Source: Authors' compilation using Vos viewer & Biblioshiny

3.8.2 Cluster 2- Policy approach and socio-economic effects of green financing

Cluster-2 (see Table 5) mainly discusses the policy approach and various socioeconomic implications around green financing and climate change. Zhang (2021) investigates how bank lending choices and collateral requirements are affected by a company's environmental performance. Further, empirical results imply that eco-friendly businesses are more likely to be granted a line of credit and less likely to be subjected to collateral restrictions throughout the sample countries. Chen (2022) tries to determine how green banking practises affected Bangladeshi private commercial banks' (PCBs) environmental performance and sources of green finance. With the use of BiH as a case example during the post-Paris

Agreement period. Cuasevic (2022) seeks to assess global public funding flows for environmental causes (2015–2020). Additionally, authors answer questions such as: *first*, what empirical evidence is there about the (efficacy of) financing for the environment, climate, and sustainability in Bosnia and Herzegovina? *Second*, what were the finance flows for BiH's DPIs in terms of the environment, the climate, and sustainability from 2015 to 2020?

Table 6- Top 5 publications in cluster 2- Policy approach and socio-economic effects of green financing

Sr. No	Article title	Author	Page rank
1	How environmental performance affects firms' access to credit: Evidence from EU countries	Zhang (2021)	0.164
2	The effect of green banking practices on banks' environmental performance and green financing: An empirical study	Chen (2022)	0.103
3	The moderating effect and threshold effect of green finance on carbon intensity: From the perspective of capital accumulation	Zhang & Ke (2022)	0.12
4	Green finance: An empirical analysis of the Green Climate Fund portfolio structure	Amighini, Guidici &Ruet (2022)	0.115
5	Analysis of international public funding flows for the environment, climate change, and sustainability: The case of Bosnia and Herzegovina	Cuasevic (2022)	0.285

Source: Authors' compilation using Vos viewer & Biblioshiny

3.8.3 Cluster 3- Green investments in macro-economic perspectives

Table 9 represents the top 10 articles in cluster 3 "Green investments in macro-economic perspectives". Dafermos, Nikolaidi and Galanis (2017) developed a stock-flow consistent methodology of Godley and Lavoie with the flow-fund model of Georgescu-Roegen to create a stock-flow-fund ecological macroeconomic model. Tolliver, Keeley and Managi (2019) investigate allocations of publicly disclosed revenues from 53 organisations' green bonds to projects and assets across 96 countries from 2008 to 2017. Irfan et al. (2022) employ difference-in-differences, mediation effects, and panel vector autoregression models to empirically examine the mechanism of influence and policy intervention effects of inclusive green funding on green innovation using regional data from China from 2010 to 2019. Feng et al. (2022) investigated the relationship between government spending and the performance of the green economy, by employing the data envelopment analysis and system GMM approaches. From an extensive review of articles in cluster-3, it is clear that studies are focusing on application of green investment in macro-economic environment. Gibon et al. (2020) assessed the life cycle of renewable energy projects which are financed through green bonds. Dmuchowski et al. (2021) emphasized green economy using green financing measures.

Table 9: Top 10 publications in cluster 3- Green investments in macro-economic perspectives

Sr. No	Article title	Author	Page rank
1	A stock-flow-fund ecological macroeconomic model	Dafermos, Nikolaidi& Galanis (2017)	0.12
2	Green bonds for the Paris agreement and sustainable development goals	Tolliver, Keeley & Managi (2019)	0.172
3	Influence mechanism between green finance and green innovation: Exploring regional policy intervention effects in China	Irfan et al. (2022)	0.267
4	Role of green finance, volatility and risk in promoting the investments in renewable energy resources in the post-covid-19	Li et al. (2022)	0.251
5	Infrastructure for China's ecologically balanced civilization	Kennedy, Zhong & Corfee-Morlot (2016)	0.092
6	Cash cows? Assembling low-carbon agriculture through green finance	Veelen (2021)	0.105
7	Nexus between government spending's and green economic performance: Role of green finance and structure effect	Feng et al. (2022)	0.307
8	Shades of green: Life cycle assessment of renewable energy projects financed through green bonds	Gibon et al. (2020))	0.048
9	The role of climate finance beyond renewables: demand-side management and carbon capture, usage and storage	Warren (2019)	0.164
10	Green economy – Growth and maintenance of the conditions of green growth at the level of Polish local authorities	Dmuchowski et al. (2021)	0.157

Source: authors' calculations

3.9 Author impact

Based on the dataset, there are 270 authors publishing research on green financing with the perspectives of climate change mitigation and environment protection. The list of most influential authors is given in Table:9. From table 8, Managi S is the most influential author with 198 citations. Followed by Zhang with total 172 citations. In terms of *h*_index, D'Orazio is the most influential author with *h*_index 4, followed by Zhang D with *h*_index 3 and Managi S with *h*_index 2.

Table 10: Influential authors based on total citations

Element	Total Citations	h_index	g_index
Managi, S.	198	2	2
Zhang, D.	172	3	3
Zhang, Z.	153	1	2
Flammer, C.	138	1	1
D'Orazio, P.	110	4	5
Aqdas, R.	93	1	1
Kumar, P.	93	1	1
Nawaz, M.	93	1	1
Patwary, A.	93	1	1
Riaz, M.	93	1	1
Seshadri, U.	93	1	1
Popoyan, L.	79	1	1
Sikora, A.	68	1	1
Crona, B.	64	1	1
Dauriach, A.	64	1	1

Source: authors' calculations

4. Discussion

The present study captures the literature on green finance with the perspective of climate change and environment protection. Sustainable economic transformation, promoting green innovation, and combating climate change all depend on the efficient application of inclusive green finance (Irfan et al., 2022). The trigger for the current study was the concept of "Green Swan". Green swans, sometimes known as "climate black swans," have many characteristics of traditional black swans. Climate-related risks often follow fat-tailed distributions; both physical and transition hazards exhibit high levels of uncertainty and nonlinearity, and it is impossible to rule out the potential of severe values (Weitzman, 2009; 2011). According to *Forbes* (2017)), an unexpected, unusual, and consequential climate event is known as a "green swan." which might conceivably pose a danger to the stability of the global banking and insurance industry when combined with a more conventional financial crisis. Hence, adequate risk mitigation of non-green, climate-exposed activities is essential to the long-term success of green finance. With this backdrop, the objective of the current study is to look extensively the studies conducted in the area of green financing as climate risk mitigation measure. Furthermore, a bibliometric analysis of the documents extracted from Scopus database is conducted. The science mapping and bibliometric analysis is conducted using Biblioshiny package of RStudio and Vosviewer. The analysis was conducted to identify the most productive authors and journals, to analyse citations and co-citations, to examine current research themes, and to identify research gaps.

The findings of the study indicated that a total of 142 documents were extracted from 77 sources from time span from 2009 to 2022. The total number of authors involved in the research for green finance and

climate change are 378. Further, in terms of annual production there has been an exponential increase in the total number of documents per year specially after 2015, the year of the Paris Agreement. Figure 1 shows in 2016 only two articles were published which in 2022 reached 70 especially in context of climate-related risk mitigation. Managi is the most influential author in terms of citations (198) with *h*_index 2, followed by D'Orazio at 110 citations with *h*_index 4. In terms of countries, China has highest numbers of publications (100) followed by UK (42), Germany (29), Italy (25), France (17) and India (13). With respect to the number of citations, China is the highest country (352 citations) followed by Germany (121 citations). Moreover, highest number collaborations are between China and Canada (3), China and France (3) and China and Japan (3). Regarding sources, *Energy Policy* is the most highly cited journal with 147 citations followed by *Sustainability* with 114 citations. Interestingly, the most frequently used keyword is green finance (61 occurrences) followed by climate change (46 occurrences).

Further, the most globally cited document is "Bibliometric analysis on green finance: Current status, development and future directions" by Zhang (2019). The study extensively explored the research done purely in green finance over the years. The most relevant affiliation is "International Institute of Affiliation Analysis" with total 10 articles published in this area. Moreover, most relevant source is *Journal of Sustainable Finance and Investment* with 14 articles and *h*_index 20.

The intellectual framework of the research field is defined by the co-citation analysis. Different research domains in green financing for climate risk mitigation have been determined in our current study using co-citation analysis. The three clusters that were created contain the new themes. The three clusters are as follows:

Cluster-1: Green financing towards climate change

Cluster-2: Policy approach and socioeconomic effects of green financing

Cluster-3: Green investments in macroeconomic perspectives

Thus, the research on current theme is concentrated in a small number of nations, authors, and journals, according to the study's findings. As a result, for further development in this field, an increasing number of nations and authors should implement green financing as a crucial component of the Sustainable Development Goals (SDGs) and for climate-related risks.

4.1 Evolution of green finance products for sustainable business practices

In recent years, the worldwide economies have witnessed the rise of diverse green financial products that promote investment in ecologically sustainable initiatives. Four primary categories of green financial goods now prevail in the market: green credit, green bonds, green insurance, and green equity.

a. *Green credit*: Green credit is a category of green financial product that significantly contributes to the advancement of green finance and the mitigation of climate change. It is in significant demand within

the green financial sector, with numerous organisations endeavouring to acquire it. Consequently, it is regarded as the most potent tool of green finance. The major objective is to diminish carbon emissions by allocating funds to energy-efficient and low-pollution production methods.

b. *Green bond*: Green bonds resemble conventional bonds; however, the proceeds are designated for project categories. Bonds are issued by governments, businesses, or financial organisations, with the issuer obligated to repay the principal and any accrued interest. Green bonds enable investors to promote environmental, social, and corporate governance (ESG) objectives. They adhere to the Green Bond Principles established by the International Capital Market Association (ICMA).

c. *Green Insurance*: Green insurance products facilitate ecological advancement and climate change mitigation by promoting conservation and the efficient production and utilisation of resources. This is a novel insurance product created by the Chinese financial sector to mitigate environmental hazards and promote ecological conservation. It emphasises environmental pollution liability to mitigate pollution and encourage sustainable production.

4.2 Strategies to be formulated for mitigation of green swan events

Bases of the findings of the studies under consideration, it is recommended:

a) Nations must cultivate an environment favourable for attracting foreign direct investment (FDI) to enhance green financing. A conventional political risk guarantee is essential in this context.
b) Governments ought to endorse policies and initiatives designed to cultivate bond markets.
c) Non-corporate entities, such as pension funds in emerging and developing nations, ought to issue green bonds.
d) Ultimately, green bonds must be established in accordance with the Green Bond Principles (GBP). This will guarantee transparency, complete disclosure, and the distribution of revenues for climate-related projects and assets.

Green finance studies provide insights into the criteria and processes for securing international funding, allowing policymakers to design strategies for leveraging external resources in the most effective way. Similar findings are quoted by (Citil, 2024) highlighting the importance of robust policies that endorse green finance, impose environmental taxes, enforce stringent regulations, facilitate strategic investments, advance environmental technologies, and promote renewable energy are essential for fostering sustainable economic growth and environmental sustainability. The first research question aims to identify the recent trends of the publication in the area of sustainable financing and climate change. The analysis of the journals and their predominant keywords reveals a trend favouring sustainability and green finance as the principal catalysts for sustainable development. The discourse can be enhanced by elucidating the mechanisms and interrelations between green finance and other variables, as derived from the findings of the most significant publications. The outcome also indicates a similar direction which is also verified by various other studies (Kristova & Hristova, 2024; y

Rasoulinezhad & Taghizadeh-Hesary 2022). A burgeoning research domain is evident in the field of sustainable financing and banking performance (Singh et al., 2024), aligning with recent and emerging trends in this field. The second research question examines the leading authors and the institutions disseminating research in this field. The analysis details about the prominent authors mentioned above and highlights an increasing interest in and acknowledgment of green finance as a vital research domain within sustainable development. The key authors also assess sustainable finance in India and the ways in which India can mitigate climate changing risk toward zero carbon policy and supporting the SDGs (Kumar, et al., 2024), and considering the interconnectedness be-tween green bond returns and sustainability indices (Abakah, et al., 2022). The third question focuses on most cited documents globally. Finance research Letters as a renowned journal lists the documents with the highest citation globally focusing on "Green finance – current trends and future challenges" mentioned in Table 3. Sustainability and climate policy journals also list out similar work in terms of publication output highlighting the global spread of research activities and significant contributions through these globally cited documents. The fourth research question identifies the principal themes in green finance and climate change, facilitating the categorization of three primary clusters in the study. (Afeef, et al., 2024) have also pointed out at the identification of green finance, facilitating the execution of sustainable development goals by enabling the reduction of global carbon emissions and mitigating the adverse effects of climate change. These aspects stand in line with the crux of three identified clusters, and address the primary concern of establishing appropriate conditions for green investment opportunities and generating interest in sustainable development projects.

5. Future Research Directions and Concluding Remarks

Based on review of literature, following research gaps are identified: The importance and ongoing relevance of green finance have been demonstrated. Since mainstream economics and finance journals have not been paying much attention to current material, there is a gap that presents opportunity for future research in at least three different paths.

First and foremost, obvious research deficit is the *"concentrated style of study",* which leaves green financing for climate risk mitigation under-researched from many parts of the world. Since, the current theme demonstrates the growing trend in usage and popularity, future scope for in this area may present a chance for aspiring scholars. The study is highly concentrated in China leaving other countries with meagre number of studies. Second, research gap *is "dearth of data"* in green financing and climate risk mitigation. There is still paucity of relevant and authentic data concerning green financing/sustainable finance/socially responsible investment for better climate-risk mitigation measures. Third, *"low coverage in mainstream finance journals"* given that green finance is fundamentally a financial topic, it is

imperative to investigate green finance challenges from a financial perspective and employ financial methods. Fourth, *"less studies in developing nations",* it would be helpful for regulators and policy makers to harmonise various policy goals and generate clearly defined policy objectives if more research were conducted on green finance challenges from developing nations' perspectives. Further, a thorough evaluation of pertinent literature is currently lacking, to the best of our knowledge. It is undoubtedly worthwhile to investigate and compare with the findings of our bibliometric investigation.

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