Navigating Biodiversity and Climate Risk: A Systematic Review and Research Agenda

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Abstract

This study employs bibliometric analysis on a corpus of 162 Scopus-indexed documents, offering a comprehensive examination of the literature on biodiversity and climate risk. The analysis reveals significant growth in publications from 2006 to 2024, with a notable peak in 2023. The highest citation count was recorded in 2020, with 1,231 citations. Irene Monasterolo and Ulrich Volz are among the most productive authors. Ulrich Volz ranks first among the most cited authors. The Journal of Sustainable Finance and Investment stands out as the most productive and Ecological Economics Journal is most cited journal. German Development Institute, Germany and Vienna University of Economics and Business, Austria are the top productive institutions. Keyword analysis highlights Sustainable Finance, Climate Change, and Climate Risk as a central theme, with emerging markets prominently featured. Christopher P.O. Reyer, Ulrich Volz, and Irene Monasterolo leads collaborative research activities, indicating strong interrelation in Biodiversity and Climate Risk.

Keywords: *Biodiversity, Climate risk, Systematic literature review, Bibliometric analysis, PRISMA framework*

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1. Introduction

In recent years, the convergence of biodiversity and climate risk has garnered heightened attention in academic and policy-making domains (Dempsey, 2016; Eckstein et al., 2021) because climate change and biodiversity loss are closely linked as direct consequences of human activities, and the economic costs and existential threats of climate change are better understood and accepted than the consequences of biodiversity loss (M. Mace, 2020). The decline of biodiversity is a serious threat to the global economy. While companies are beginning to take strategic action, a significant part of their value remains vulnerable to unmanaged biodiversity risks (Carvalho et al., 2023). Conserving biodiversity is becoming a significant challenge for sustainable finance, needing hundreds of billions in private investment each year. However, there's a noticeable gap in research within the finance literature on how to tackle this issue (Karolyi & Tobin-de La Puente, 2022).

Biodiversity and climate risk have become significantly important because of their impact on economic stability, investment portfolios, and long-term financial strategies (Thompson, 2023). Park and Kim (2020) point out that the financial sector is recognising the importance of environmental sustainability for economic resilience and effective risk management, moving past just ethical or ecological considerations. The growing importance of such factors indicates that the changing weather of the world is aggravating day by day and thus causing unforeseen disturbances in natural systems as well as in market forces of power (Abbass et al., 2022). The significant rise in monetary losses due to climate risks have made financial institutions as well as policymakers focus more upon the ESG factors while framing planning (Zhai et al., 2024; Li, 2024).

International conventions have significantly influenced how the world responds to these challenges. Among the major treaties, this loss is addressed by the Convention on Biological

Diversity which was established in the Earth Summit in Rio de Janeiro in 1992 (Barton, 1992; Swanson, 2013). The primary goals are the conservation of biological diversity, the use of its components in a sustainable manner, and the fair and equitable sharing of benefits arising from the use of genetic resources (Aguilar, 2001). Similarly, UNFCCC, adopted by the same summit, gives a framework for international efforts aimed at fighting climate change and its impacts (Hermwille et al., 2017; Kinley et al., 2021).

Previous literature shows that in the area of biodiversity and climate risk, scientists and researchers mostly focused on ecology, environmental economics, public policy, and social sciences disciplines. Ecological studies look at how climate change impacts where species live and how ecosystems work. The economics literature explores the value that ecosystem services bring to our economy and the costs associated with losing biodiversity (Kumar, 2010). Research focused on policy has looked into how well international agreements like the CBD and the UNFCCC tackle these interconnected challenges (Biedenkopf, 2017). So far, social science research has primarily focused on the social consequences of climate change-induced changes in biodiversity, as well as the importance of indigenous and local knowledge in conservation efforts (Rahman & Alam, 2016).

The relationship between biodiversity and climate risk emphasizes the importance of global cooperation through conventions that align environmental objectives. The CBD Kunming-Montreal Global Biodiversity Framework and the UNFCCC's Paris Agreement highlight the necessity of working together to tackle biodiversity and climate risk, aiming to protect the natural systems essential for our survival (Pörtner et al., 2023). In this regard, framework and agreement both promote holistic approaches that are important for building resilience and sustainable development in the face of growing environmental risks.

Currently most of the researchers are focusing only on how biodiversity and climate risk are connected but there is a big gap in research about how these complex connections affect financial markets in new ways. In addition, policy-oriented and social science research looks at the broad effects of biodiversity and climatic change and analyses of how risks directly impact economic frameworks and investment strategies have been more limited. This gap shows the need for interdisciplinary research that would combine ecological complexity with new models of financial risk management. It would ensure more efficient resiliency and sustainability in economic planning. Based on this basis, this gap also points to the need to examine a comprehensive review of existing literature and focus on enhancing theoretical understanding that would influence policy and practice in biodiversity and climate risk areas. This review will be used to understand the various views of the relationship between biodiversity and climate risk through an extensive analysis of the existing literature. For this purpose, we conduct a scientific bibliometric analysis that determines the important bibliometric features and research topics relevant to this study (Basu et al., 2023; Bhaskar et al., 2022, 2023; Cumming et al., 2023; Donthu et al., 2021; Kumar et al., 2023; Lal et al., 2022, 2023; Mukherjee et al., 2022; Pandey et al., 2023, 2024; Kumari & Jaiswal, 2024). This bibliometric review seeks to highlight the trends and directions of existing studies on biodiversity and climate risk, thereby offering insights for future research directions. This extensive review is a significant effort to explore the intersection of biodiversity, and climate risk from a bibliometric perspective, highlighting current themes and future research prospects. Accordingly, we specifically investigate several research questions (RQs):

RQ1. *What are publication and citation trends in the literature on Biodiversity and Climate risk?*

RQ2. *What are the conceptual structure (articles, sources, authors, and institutions) in Biodiversity and Climate risk?*

RQ3. *How do authors, sources, countries, and documents on Biodiversity and Climate risk engage in bibliographic coupling?*

RQ4. *What do the keywords co-occurrence analysis and co-authorship network reveal about Biodiversity and Climate risk?*

RQ5. *Where should future research focus to enhance understanding of the relationship between Biodiversity and Climate risk?*

The subsequent sections of the paper are structured in the following manner: Section 2 outlines the methodology employed in the study. The findings of the bibliometric analysis are presented in Section 3. Section 4 presents the conclusions and examines the findings. Ultimately, Section 5 outlines the future research directions from this study.

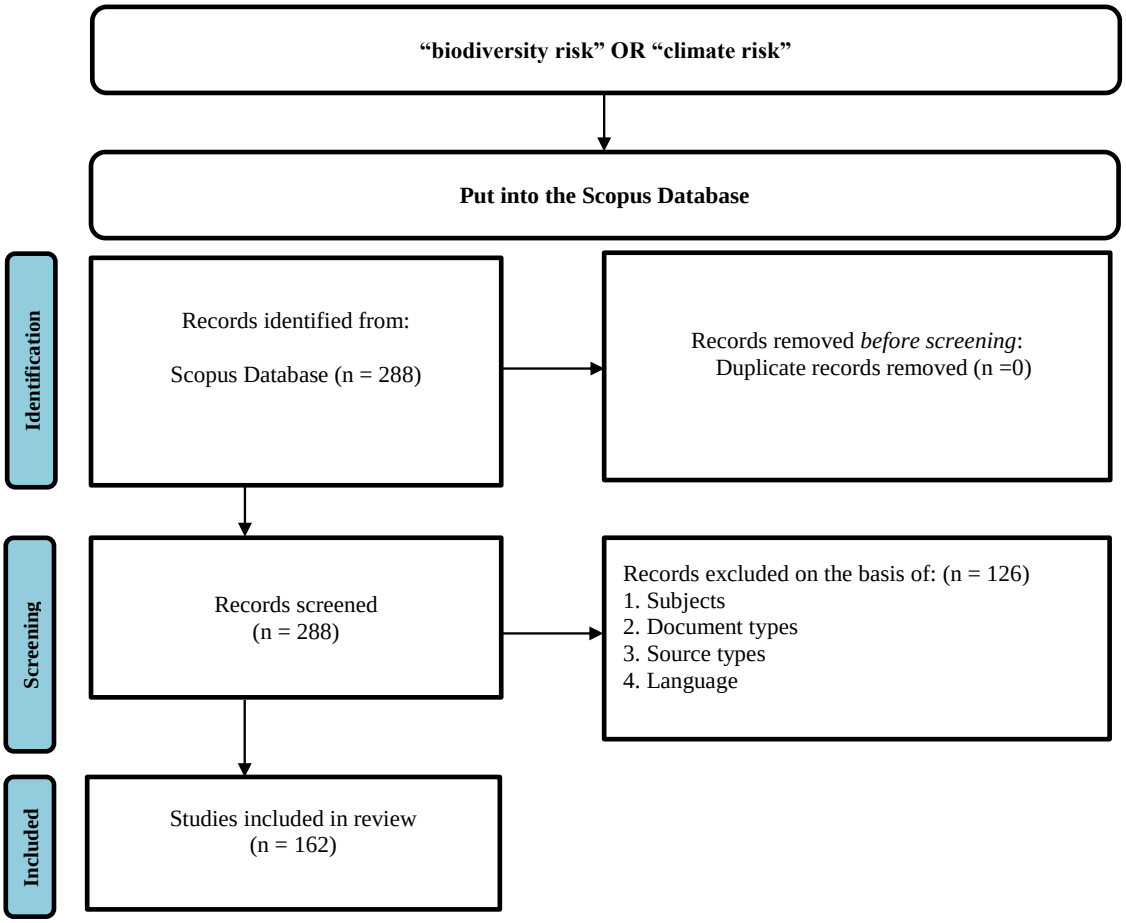

Figure 1. PRISMA Framework 2020

2. Research Methodology

The present article provides a comprehensive review of the literature on Biodiversity and Climate Risk, employing bibliometric analysis to quantify and qualitatively evaluate research papers. Gephi and Biblioshiny software were used in this study to demonstrate the network analysis and locate information about the conceptual structure (Viswalekshmi et al., 2023; Majiwala & Kant, 2023; Jaiswal et al., 2024). Gephi software helps to easily visualize and analyse networks such as keyword co-occurrence, citation patterns, co-authorship networks, and bibliographic coupling (Kocak et al., 2019). In contrast, Biblioshiny software help us to collect and examine the data across multiple dimensions in thematic mapping, document analysis, and conceptual structuring (Mougenot & Doussoulin, 2023). Furthermore, we used the PRISMA framework for systematically extract the document which defines the search terms used to access all articles relevant to this analysis (see Figure 1).

2.1. Defining search query

This study extracted the document through using the Scopus database, being among the biggest and most credible alternatives for the Web of Science, as presented in Mahato et al., 2023; Jaiswal et al., 2024. and Harzing and Alakangas, 2016. A comprehensive literature review of international studies on biodiversity risk and climate risk has been conducted between 2006 and 21 October 2024. The search was done using the words "climate risk" and "biodiversity risk," searching on titles, abstracts, and keywords to ensure it was in line with the main goals of the study. We verified the search string so that it should basically trace previously known research papers that would help us retrieve as many relevant documents about that particular topic as possible.

2.2. Refinement of search results

After applying the search string discussed above, we were able to retrieve 288 documents from the Scopus database until October 21, 2024, as shown in figure 1. All these are published document types such as articles and review papers since they are more critically reviewed (Lim et al., 2022). We narrow down our focus even further to journals. They are an important source for the knowledge base in the areas of various topics closely related to biodiversity and climate risk in the environment and economics. Conclusion We selected 162 documents in English for a bibliometric analysis using the above criteria.

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	2	1.23	Good
CR	Cited References	4	2.47	Good
DI	DOI	7	4.32	Good
DE	Keywords	13	8.02	Good
RP	Corresponding Author	24	14.81	Acceptable
ID	Keywords Plus	91	56.17	Critical
WC	Science Categories	162	100.00	Completely missing

Figure 2. Completeness of bibliographic metadata - 162 documents from Scopus (Source: Biblioshiny)

3. Results of bibliometric analysis

According to Paul and Criado (2020), four major types of systematic literature reviews exist in the literature: domain-based, theory-based, method-based, and meta-analytical reviews. A bibliometric analysis is classified as a domain-based systematic literature review. This type of review emphasizes the collection and use of quantitative data to describe, evaluate, and monitor published literature on a specific topic (Donthu et al., 2021). Such an approach is helpful in research analysis based on issues of interest, related literature documents, social networks, great publishers, and key publications. The article uses bibliometry in researching a huge pool of scientific information in an area with both established and ongoing researches. Bibliometric research helps scholars find future research trajectories in relevant fields, right

publication outlets, relevant contributions, and influential authors on the basis of citation numbers and research trends (Agbo et al., 2021).

3.1. Completeness of bibliographic metadata

Figure 2. Completeness of bibliographic metadata for 162 documents: overall quality and coverage of key metadata fields. The figures also indicate considerable discrepancies in completeness of the different elements. All the core bibliographic fields, including Abstract (AB), Author (AU), Document Type (DT), Journal (SO), Language (LA), Publication Year (PY), Title (TI), and Total Citation (TC), are complete, meaning no missing values. Fields in general indicate a necessity of proper data management through the whole dataset to strengthen the same for citation indexing and scholarly visibility. All of these fields, namely, Affiliation (C1), Cited References (CR), DOI (DI), Keywords, (DE) had between 1.23%, 8.02 % missing values but were encountered altogether in "Good" quality. Missing values in these fields, while not harmful, may have a minor effect on the dataset's completeness in some analyses. However, a significant gap has been identified in the Corresponding Author (RP) field, with a missing rate of 14.81%, which is identified as "acceptable." This has the potential to obstruct communication with the primary authors of a substantial number of publications. The Keywords Plus (ID) field is missing in 56.17% of cases, and that's quite concerning. This may negatively affect how easily documents can be found and how well they are indexed. The lack of the Science Categories (WC) field, which is totally absent, presents a major challenge for identifying documents by scientific disciplines. This gap could hinder effective retrieval and analysis across various fields.

3.2. Main Information:

Figure 3 presents a comprehensive analysis of the characteristics of 162 documents obtained from Scopus, examined using Biblioshiny, spanning the period from 2006 to October 21, 2024. The dataset showcases a wide array of publication outlets, comprising contributions from 97 sources and 476 authors. It includes 31 single-authored papers, highlighting a trend towards collaborative efforts, as demonstrated by an average of 3.22 co-authors per document. Significantly, 40.12% of the papers feature international co-authorship, highlighting the worldwide aspect of the study. The dataset contains a wealth of unique terms, showcasing 544 distinct entries, and demonstrates significant academic involvement with a total of 11,003 references. The documents exhibit an average age of 2.69 years, indicating that the dataset remains quite current, with an average of 17.57 citations per document, underscoring their citation impact and visibility within the academic community. Furthermore, the 17.05% annual growth rate indicates a notable enhancement in productivity throughout the period.

Figure 3. Characteristics of the sample documents (Source: Biblioshiny)

3.3. Trend in publications and citations:

Table 1 presents the publication and citation trends from 2006 to Oct 21, 2024. It reveals significant fluctuations in scholarly output and corresponding impact as reflected by citation metrics. Initially, from 2006 to 2012, there was minimal research output, with only three publications distributed in six years. However, a marked increase in productivity is observed beginning in 2013, with publication counts rising steadily, peaking in 2023 with 54 publications. This upward trend in publications aligns with a general increase in citations, particularly notable in 2021, where a high citation count (854.91) corresponds to a modest increase in average citations per publication (40.71). Despite this peak, average citations per publication saw a decline in 2022 and 2023, suggesting a shift in the impact or relevance of recent publications or an increase in less frequently cited works. The significant drop in average citations to 2.35 in 2024 reflects either a short timeframe for citation accumulation or a decrease in citation impact. This dataset underscores a trajectory of accelerated scholarly output with variable citation rates, potentially indicating shifts in research quality, focus areas, or the saturation of previously explored topics.

Table 1. Publications and citations trend

Year	Publications	Citations	Average Citations
2006	1	78	78.00
2009	1	48	48.00
2012	1	51	51.00
2013	2	144	72.00
2014	2	48	24.00
2015	2	38	19.00
2017	5	193	38.60
2018	4	84	21.00
2019	7	193.97	27.71
2020	15	385.95	25.73
2021	21	854.91	40.71
2022	30	401.1	13.37
2023	54	286.74	5.31
2024	17	39.95	2.35

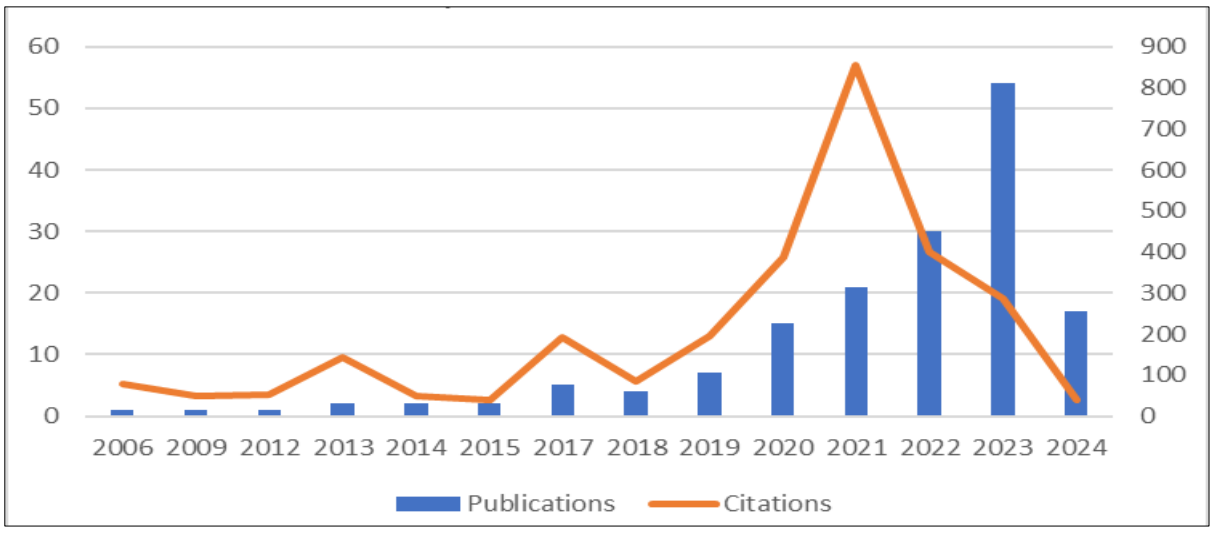

Figure 4. Trend in Publication and Citations

3.4. Most productive authors and most cited authors

Table 2 presents a comprehensive overview of the leading authors in the domains of biodiversity and climate risk, highlighting essential metrics including document count, citation count, and citations per document. Irene Monasterolo and Ulrich Volz are distinguished for their

productivity, each having authored six documents. Nevertheless, Volz's citation count is significantly higher at 360, averaging 60 citations per document, indicating a substantial impact and acknowledgement of his contributions. Stefano Battiston, with just two documents yet an impressive 56 citations per document, showcases significant research impact despite a lower output volume. This mirrors the influence seen in authors such as Jeroen Aerts and Sam Barrett, both of whom also maintain citations per document exceeding 50. Hugues Chenet stands out with the highest citation per document at 73, despite having published only two documents. This underscores the significant impact of his contributions in relation to his publication count. Although various authors, including Campiglio, Knaepen, and Magnuszewski, produce significant contributions, their citations per document tend to be more moderate, typically ranging from the mid-to-low twenties to the teens. This distribution showcases a variety of productivity and citation impact among authors, highlighting both prolific and selective contributors to the discipline.

3.5. Most cited documents

The first article is titled "Central bank mandates, sustainability objectives and the promotion of green finance" authored by Dikau (2021), appearing in Ecological Economics, and has garnered 199 citations. The second article is "Climate Finance" by Giglio (2021) from the Annual Review of Financial Economics, which has been cited 144 times. The third article, "Local Level Climate Justice?" The article "Adaptation finance and vulnerability reduction" authored by Barrett in 2013, published in Global Environmental Change, has garnered 102 citations. The fourth study, titled "The impact of climate vulnerability on firms' cost of capital and access to finance" by Kling (2021) published in World Development, has garnered 100 citations. The fifth article, titled "Opportunities for knowledge co-production across the energy-food-water nexus: Making interdisciplinary approaches work for better climate decision making" by Howarth (2017) in Environmental Science and Policy, has been cited 98 times.

Table 2. Top productive and cited authors

Authors	Documents	Citations	C/D
"Monasterolo, Irene"	6	234	39
"Volz, Ulrich"	6	360	60
"Taylor, Zac J."	3	68	22.67
"Battiston, Stefano"	2	112	56
"Aerts, Jeroen C.J.H."	2	105	52.5
"Barrett, Sam"	2	107	53.5
"Campiglio, Emanuele"	2	34	17
"Chenet, Hugues"	2	146	73
"D'Amato, Valeria"	2	46	23
"D' Ecclesia, Rita"	2	46	23
"Knaepen, Hanne"	2	34	17
"Levantesi, Susanna"	2	46	23
"Magnuszewski, Piotr"	2	34	17
"Mirza, Nawazish"	2	36	18
"Reyer, Christopher P.O."	2	34	17

Notes: C/D indicates citations per document

The sixth article is called "Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy," written by Chenet in 2021 and published in Ecological Economics. It has received 93 citations. The seventh article, "The impact of climate change on incomes and convergence in Africa," written by Baarsch in 2020 and published in World Development, has received 82 citations. Roncoroni's (2021) article, titled "Climate risk and financial stability in the network of banks and investment funds," published in the Journal of Financial Stability, has received 81 citations. The ninth article, "Business risk and the emergence of climate analytics," authored by Fiedler in 2021 and published in Nature Climate Change, received 79 citations. The tenth article, titled "Climate change, risk factors and stock

returns: A review of the literature," authored by Venturini in 2022 and published in the International Review of Financial Analysis, has garnered 71 citations.

The eleventh article, "Environmental Finance: An Interdisciplinary Review" by Tao (2022) in Technological Forecasting and Social Change, has received 70 citations. The twelfth entry, "Adaptation to Climate Change," written by Fankhauser in 2017 and published in the Annual Review of Resource Economics, has received 58 citations. The thirteenth article, "The impacts of climate change risks on financial performance of the mining industry: Evidence from listed companies in China" by Sun (2020) in Resources Policy, has received 55 citations. Schumacher's article, "Sustainable finance in Japan," published in 2020 in the Journal of Sustainable Finance and Investment, has received 53 citations.

Table 3. Top cited documents

Rank	Title	Authors and Year	Source	Citation
1.	"Central bank mandates, sustainability objectives and the promotion of green finance"	Dikau (2021)	"Ecological Economics"	199
2.	"Climate Finance"	Giglio (2021)	"Annual Review of Financial Economics"	144
3.	"Local level climate justice? Adaptation finance and vulnerability reduction"	Barrett (2013)	"Global Environmental Change"	102
4.	"The impact of climate vulnerability on firms' cost of capital and access to finance"	Kling (2021)	"World Development"	100
5.	"Opportunities for knowledge co-production across the energy-food-water nexus: Making interdisciplinary approaches work for better climate decision making"	Howarth (2017)	"Environmental Science and Policy"	98
6.	"Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy"	Chenet (2021)	"Ecological Economics"	93
7.	"The impact of climate change on incomes and convergence in Africa"	Baarsch (2020)	"World Development"	82
8.	"Climate risk and financial stability in the network of banks and investment funds"	Roncoroni (2021)	"Journal of Financial Stability"	81
9.	"Business risk and the emergence of climate analytics"	Fiedler (2021)	"nature climate change"	79
10.	"Climate change, risk factors and stock returns: A review of the literature"	Venturini (2022)	"International Review of Financial Analysis"	71
11.	"Environmental Finance: An Interdisciplinary Review"	Tao (2022)	"Technological Forecasting and Social Change"	70
12.	"Adaptation to Climate Change"	Fankhauser (2017)	"Annual Review of Resource Economics"	58
13.	"The impacts of climate change risks on financial performance of mining industry: Evidence from listed companies in China"	Sun (2020)	"Resources Policy"	55
14.	"Sustainable finance in Japan"	Schumacher (2020)	"Journal of Sustainable Finance and Investment"	53

3.6. Most productive journals and most cited journals

Table 4 shows the most productive and frequently cited sources in the field of biodiversity and climate risk. These sources cover a wide range of topics important to the advancement of knowledge in sustainability, climate change, and environmental finance. Ecological Economics is the journal with the most citations per document (79.20), indicating its importance in the field. The journals World Development and Global Environmental Change have impressive citation rates, with citations per document at 60.67 and 55, respectively, demonstrating their importance in the academic community. Nature Climate Change and Environmental Science and Policy are also influential journals, with each receiving more than 50 citations per document, highlighting their importance in the ongoing discussion. The Journal of Sustainable Finance and Investment is the most productive, with 11 documents and an impressive citation per document rate of 15.55. Sustainability (Switzerland) follows closely with seven publications, as does Climate Risk Management with six.

3.7. Most productive institutions

Table 5 displays the most productive institution in the domain of biodiversity and climate change. The Vienna University of Economics and Business in Austria is a leading contributor, attaining the highest citation per document rate of 28.33 from three publications, indicating substantial research impact per publication. The German Development Institute in Bonn, Germany, has a significant citation per document rate of 20 from three documents, highlighting the impact of its publications. The Excelia Business School in France and the Potsdam Institute for Climate Change Research in Germany exhibit notable productivity, with citations per document of 18 and 17, respectively. This indicates a significant impact of their research, despite a lower volume of published documents. Furthermore, institutions such as the Institute for Sustainable Resources at University College London and the Mediterranean School of Business in Tunisia exhibit a range of citations per document, reflecting the differing impact and scope of their contributions. The data indicates a wide-ranging international framework of high-impact research originating from specialised institutions in various regions, especially Europe and North America, underscoring global collaborative initiatives in the advancement of business, economics, and sustainability scholarship.

Table 4. Top productive journals and cited journals

Sources	Documents	Citations	C/D
“Journal of Sustainable Finance and Investment”	11	171	15.55
“Sustainability (Switzerland)”	7	94	13.43
“Climate Risk Management”	6	61	10.17
“Ecological Economics”	5	396	79.20
“International Review of Financial Analysis”	4	103	25.75
“Journal of Financial Stability”	3	107	35.67
“Global Environmental Change”	3	165	55.00
“Technological Forecasting and Social Change”	3	106	35.33
“World Development”	3	182	60.67
“Nature Climate Change”	2	105	52.50
“Annals of the American Association of Geographers”	2	27	13.50
“Cities”	2	45	22.50
“Environmental Science and Policy”	2	104	52.00
“Geoforum”	2	28	14.00
“Journal Of Cleaner Production”	2	42	21.00

Notes: C/D indicates citations per document

3.8. Co-occurrence analysis of author's keyword

Figure 5 illustrates a keyword co-occurrence network, created with Gephi software, which emphasises the interrelations among principal research themes in sustainable finance and climate risk. The significance of terms like Sustainable Finance, Climate Change, and Climate

Risk highlights their importance in academic discussions, acting as crucial connections among various related subjects. Critical themes encompass Green Finance, Systemic Risk, and Transition Risk, which are linked to sub-topics including ESG, Climate Finance, Risk Management, and Financial Stability. The network indicates that emerging areas like Biodiversity Risk, Machine Learning, and Green Bonds are increasingly relevant, extending from the core themes. The incorporation of policy-related terms like TCFD and Paris Agreement underscores the integration of global climate governance frameworks within financial discussions. The thickness of the connections signifies frequent co-occurrences, demonstrating a substantial level of thematic interdependence. This network highlights the interdisciplinary aspects of research in sustainable finance, demonstrating the intricate relationships among financial systems, environmental risks, and global sustainability goals.

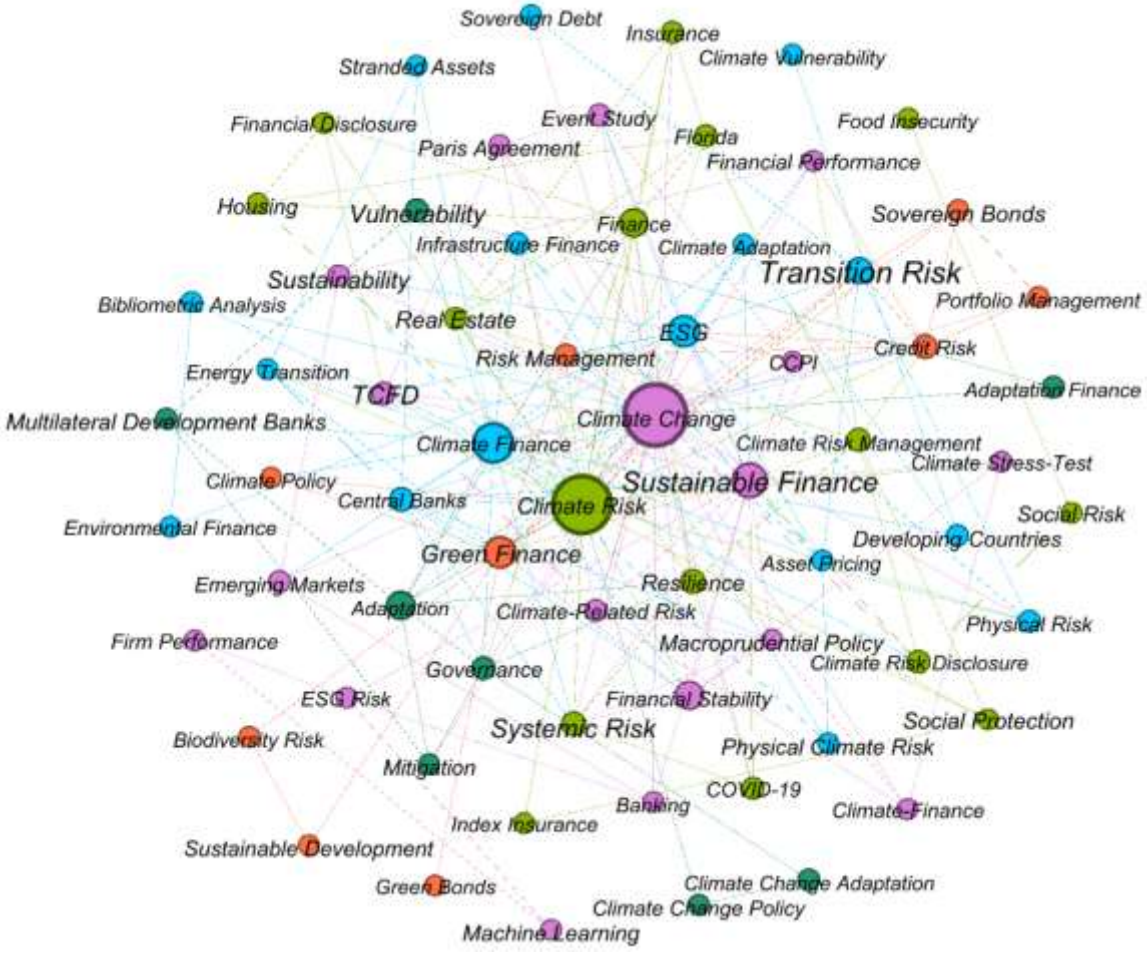

Figure 5. Keyword co-occurrences (Source: Gephi)

3.9. Co-authorship network analysis of authors

Figure 6 illustrates the co-authorship network, visualised using Gephi software, highlighting the interconnected scholarly relationships among researchers within a specific field. Figure 5 illustrates that Christopher P.O. Reyer, Ulrich Volz, and Irene Monasterolo are central nodes, as evidenced by their larger, more prominent circles, which signify elevated levels of collaboration and influence within the network. The authors identify several clusters, indicating their function as bridging entities that promote collaboration among disparate research groups. Researchers such as Hugues Chenet and Emanuele Campiglio contribute significantly to the integration of clusters, demonstrating a collaborative research approach across diverse subfields and institutions. This network emphasises the interdisciplinary and

international characteristics of the academic community, illustrating the power of collaborative efforts and the dissemination of scholarly influence among various research contributors.

Table 5. Top productive institutions

Organization	Documents	Citations	C/D
"Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon"	4	36	9
"German Development Institute, Bonn, Germany"	3	60	20
"Vienna University of Economics and Business, Austria"	3	85	28.33
"Mediterranean School of Business, South Mediterranean University, Tunis, Tunisia"	2	3	1.50
"P. G. Department of Commerce, Magadh University, Bodh Gaya, India"	2	11	5.50
"Copenhagen Business School, Department of Economics, Porcelænshaven 16a, Frederiksberg, Dk-2000, Denmark"	2	7	3.50
"Delft University of Technology, Netherlands"	2	3	1.50
"Durham University, United Kingdom"	2	3	1.50
"Excelia Business School, La Rochelle, France"	2	36	18
"Global Development Policy Center, Boston University, United States"	2	18	9
"Institute for Sustainable Resources, University College London, London, United Kingdom"	2	53	26.50
"Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore"	2	7	3.50
"Potsdam Institute for Climate Change Research (Pik), Member of the Leibniz Association, Telegrafenberg, P.O. Box 601203, Potsdam, 14412, Germany"	2	34	17
"Stockholm Environment Institute York, Department of Environment and Geography, University of York, Yo10 5ng, United Kingdom"	2	34	17
"The World Bank, United States"	2	24	12

Notes: C/D indicates citations per document

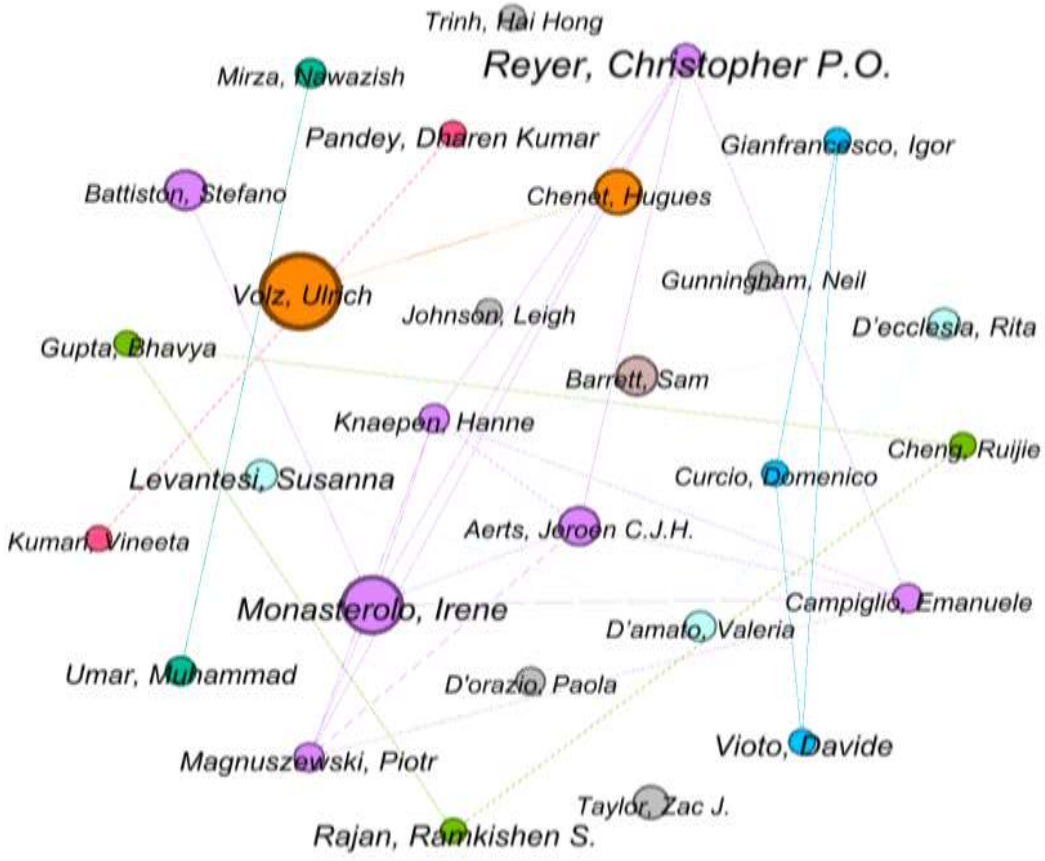

Figure 6. Co-authorship network (Source: Gephi)

3.10. Co-authorship network analysis of countries

Figure 7 shows patterns of international research cooperation produced by Gephi software, so displaying a co-authorship network among nations. The network graph shows nations represented by nodes whose size reflects the importance of each nation in collaborative research projects. Larger nodes, such as the United States, the United Kingdom, and Germany, show high participation in international research collaborations. The connections represented by lines between nodes indicate the strength and frequency of co-authorship between countries, whereas thicker lines indicate stronger collaborative relationships. This network visualisation shows the importance of global research networks, with countries such as the United States and the United Kingdom working as central hubs for extensive cross-border knowledge sharing. The different colors of nodes may point to different clusters within the network, potentially representing geographic, linguistic, or field-specific collaborations, showing the complex nature of global research dynamics.

3.11. Bibliographic coupling

Bibliographic coupling is a technique in both bibliometrics and information sciences that compares two documents based on shared references or citations. It connects two documents when they have a common reference; increasing the number of common citations increases the strength of the relationship between the connected documents (Pandey et al., 2024). This method is mostly used in the research area to identify thematic cluster mapping and the examination of scholarly networks (Rousseau et al., 2018). There are four types of bibliographic coupling: author level, journal level, country level, and document level. We will cover all of the topics listed above.

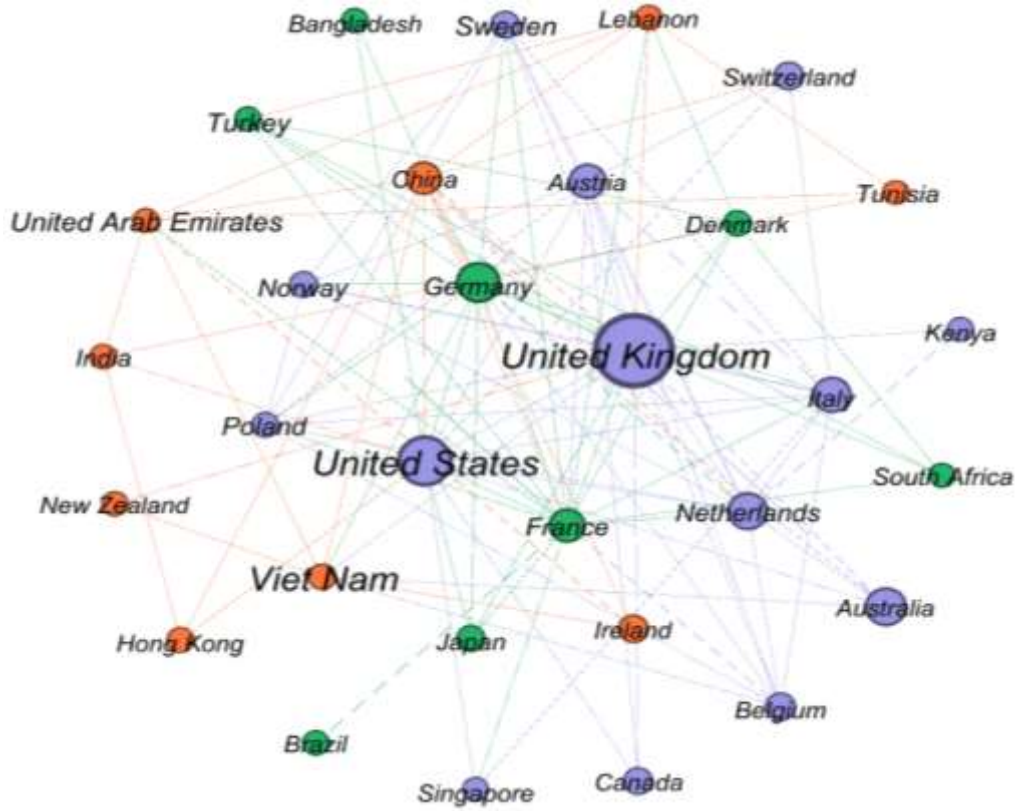

Figure 7. Co-authorship network of countries (Source: vosViewer and Gephi)

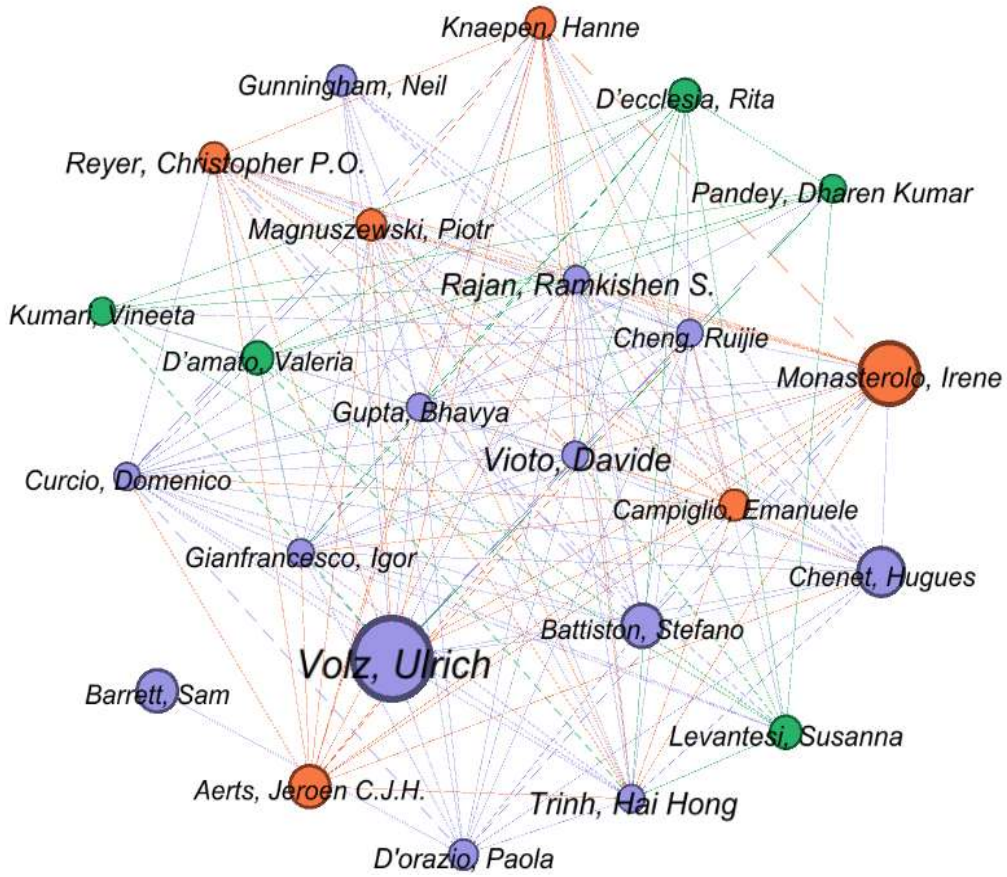

Figure 8. Bibliographic coupling of authors (Source: Gephi)

3.12. Bibliographic coupling of authors

Author coupling occurs when two authors refer to the same sources. This method identifies the intellectual connections or collaborative ties between people who share common interests. A minimum threshold of two documents and five citations was established, resulting in the identification of 478 authors. This coupling method produced a finding of 28 different clusters, 24 of which represented authors who were frequently co-cited in related research themes. Figure 8 shows the bibliographic coupling network of authors created with VOS viewer and Gephi. In that network, each node represents an author, with node size reflecting the author's level of connectivity within the bibliographic coupling structure. Famous authors, such as Ulrich Volz and Davide Vioto, have larger nodes, showing a high degree of shared references with other researchers and showing their central position in the displayed research domain. The connections between nodes indicate the strength of bibliographic coupling, with thicker lines indicating higher levels of shared literature, intellectual commonality, or shared thematic interests. The network structure reveals clusters of authors who frequently cite the same sources, indicating thematic relationships. This visualisation shows key scholars and collaborative groups, providing insights into the research domain's intellectual framework and identifying potential scholarly impact centers.

3.13. Bibliographic coupling of journals

Journal bibliographic coupling occurs when journals are linked together by citing the same references in multiple articles. This method is frequently used to investigate specific domains and identify thematic relationships between publications. An analysis of journals with at least two documents and five citations yielded the identification of 97 journals organised into 27 clusters. This analysis points out important publication venues that are significant for understanding climate finance and policy. Figure 9 presents the bibliographic coupling network

of academic journals through VOS viewer and Gephi. This network indicates that each node is a journal, and every node represents the degree to which a journal is interconnected, emphasizing how influential it has been for the journals themselves and those around them. Smaller nodes mean the influential yet rare co-citation patterns of the minor journals like the Wiley Interdisciplinary Reviews: Climate Change, Nature Climate Change, and the Journal of Sustainable Finance and Investment. Links between the nodes are demonstrated to be strong in accordance with how many shared references the thicker lines have to highlight the areas of intellectual commonality. It identifies clusters of citing journals, which frequently cites similar sources and therefore indicates overlap in thematic concerns and research related to issues such as sustainability, climate change, and financial stability. The bibliographic coupling map is a network that would indicate the key journal in the field and allow for visualization of research hubs, thereby indicating knowledge clustering and dissemination across related journals.

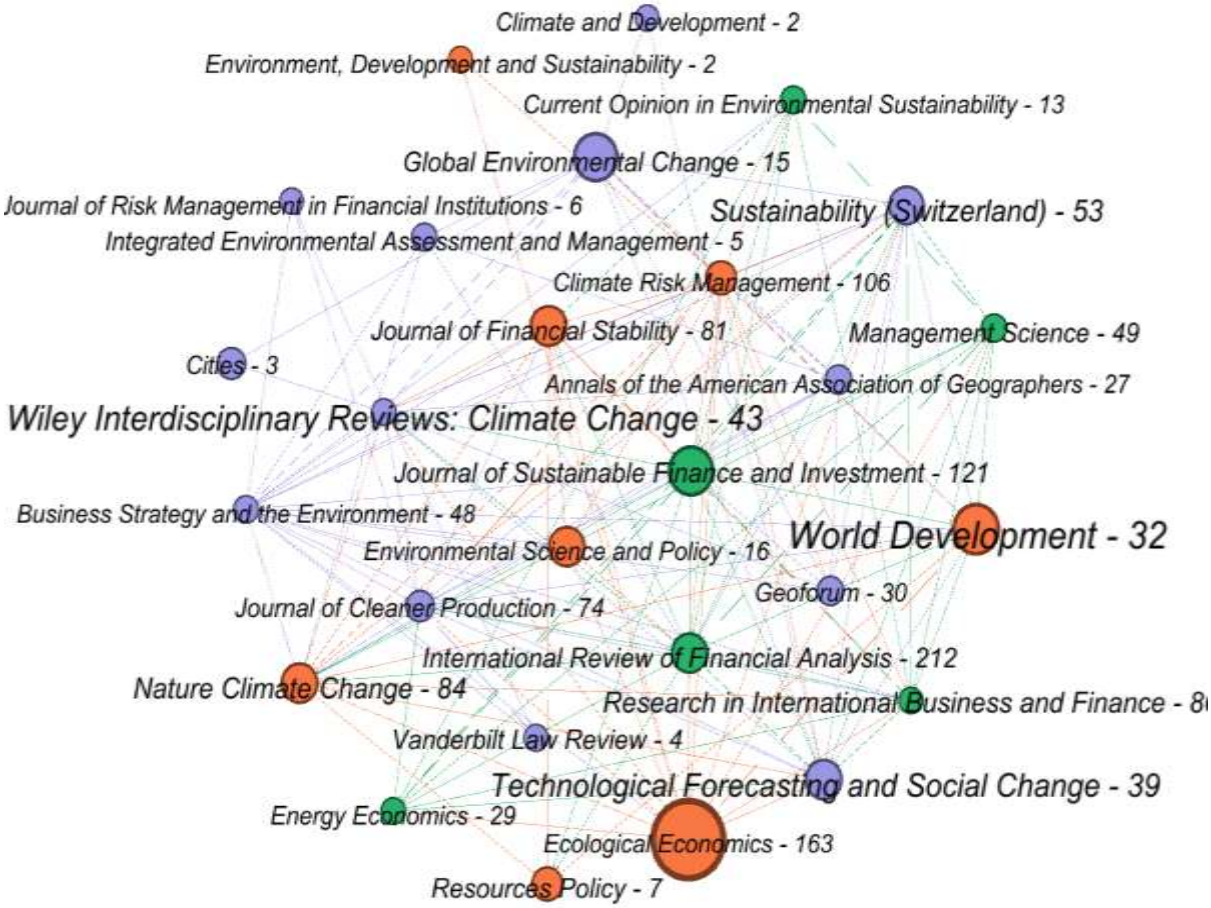

Figure 9. Bibliographic coupling of journals (Source: Gephi)

3.14. Bibliographic coupling of countries

Researchers from different nations may connect through bibliographic coupling when they cite the same works in their publications. This approach helps to understand global research networks within a field and to form international collaborations. National-level studies through bibliographic coupling determined 59 countries, of which 31 fell into categories under a minimum of two documents and five citations. This method identifies areas of co-cited research interests in the topics of climate and finance, thus a global trend in collaborative research. It is shown in Figure 10 that the bibliographic coupling network between nations graphically presents international research ties based on shared bibliographic references. The size of each node refers to the nation and, therefore, will indicate the nation's influence and involvement within the global research framework. Larger nodes indicate that the US, UK, and Germany

play important roles and share citations with other nations. Their leadership in knowledge production and dissemination is highlighted. Strong bibliographic coupling between nodes is indicated by thicker lines, indicating a larger shared reference base between countries and strong research collaborations and intellectual commonality. Clusters of countries with strong bibliographic connections indicate thematic or regional research overlap in this network map. This figure shows how international scholarship is interconnected, emphasizing the need for global collaboration to advance research agendas.

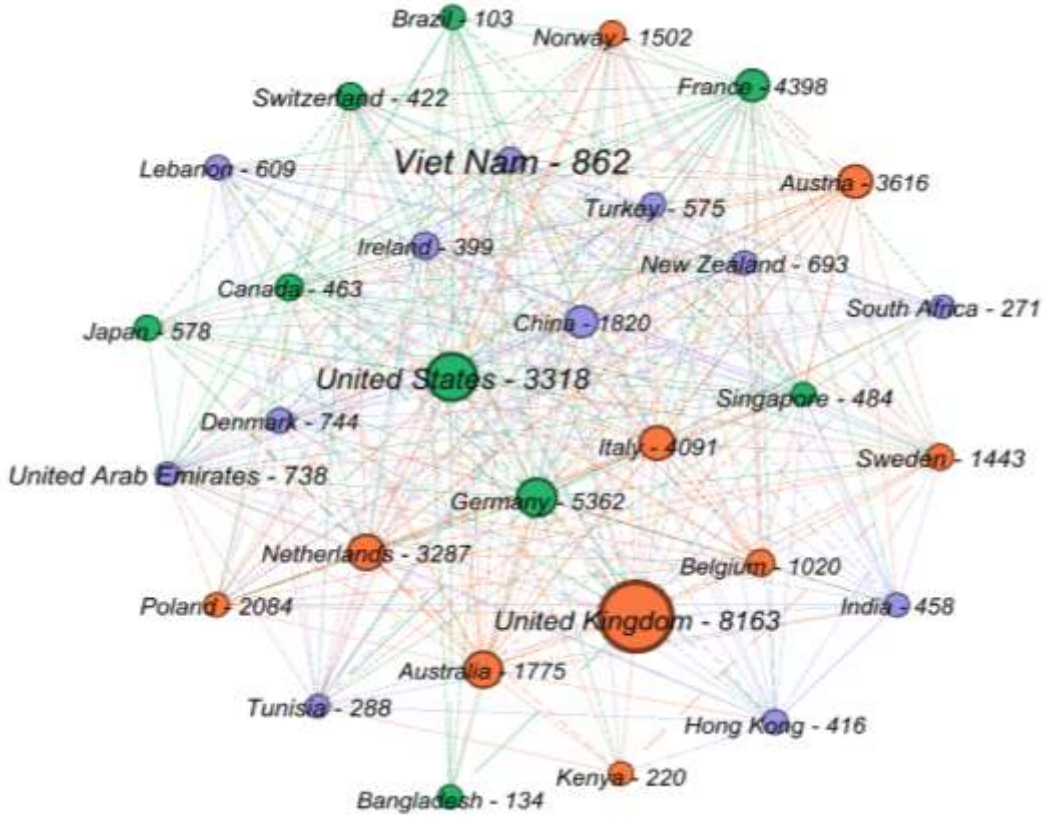

Figure 10. Bibliographic coupling of countries (Source: Gephi)

3.15. Bibliographic coupling of documents

The primary goal of this analysis is to understand the connections between individual documents or papers. Documents used for reference sharing are termed "coupled." This method enables the recognition of relevant studies or contributions within a specific domain. Document-Level Bibliography Coupling entailed examining documents with at least 5 citations, which yielded 162 documents divided into 96 clusters, 80 of which showed interconnections. This detailed approach identifies particular research articles which show that there are some thematic relationships between climate finance and policy.

3.15.1. Climate Resilience and Strategic Financial Adaptation:

This cluster analyses 25 documents related to climate change and finance. Numerous studies highlight the importance of strategic resilience in utilizing COVID-19 to inform climate policies and address systemic, transboundary risks (Ringsmuth et al., 2022). Gambhir et al. (2021) proposed a framework for the analysis of short-term transition risks and long-term physical risks associated with greenhouse gas emissions and increasing temperatures. Antoniuk and Leirvik (2021) found the impact of political events on returns in climate-sensitive sectors, whereas Adhikari and Chalkasra (2021) investigated the challenges associated with private-sector investments in climate adaptation. Most of the studies investigate sustainable finance, including Ngo et al. (2022), who analyze climate disclosures in line with the Taskforce on

Climate-Related Financial Disclosures (TCFD), and Cheung et al. (2021), who present a framework to identify barriers and enablers to sustainable home loan finance. Zitti and Guttormsen (2022) evaluate climate disclosures in salmon aquaculture and emphasize the need for transparency to foster a low-carbon economy. De Angelis et al. (2022) investigated the impact of green investing on corporate carbon reduction. Monasterolo et al. (2018, 2019) advance climate stress-testing methodologies and models that extend beyond traditional finance to assess climate impacts. Dikau and Volz (2021) and Gunningham (2020) examine the sustainability roles of central banks and suggest policy instruments aimed at facilitating low-carbon investments. Agarwala et al. (2021) shows a taxonomy for evaluating climate impacts on sovereign risk. Furthermore, Chenet et al. (2021) advocate for a precautionary policy framework as an alternative to market-based climate risk strategies. Cormack et al. (2021) investigate the financial implications of EU carbon reduction policies on electric utilities.

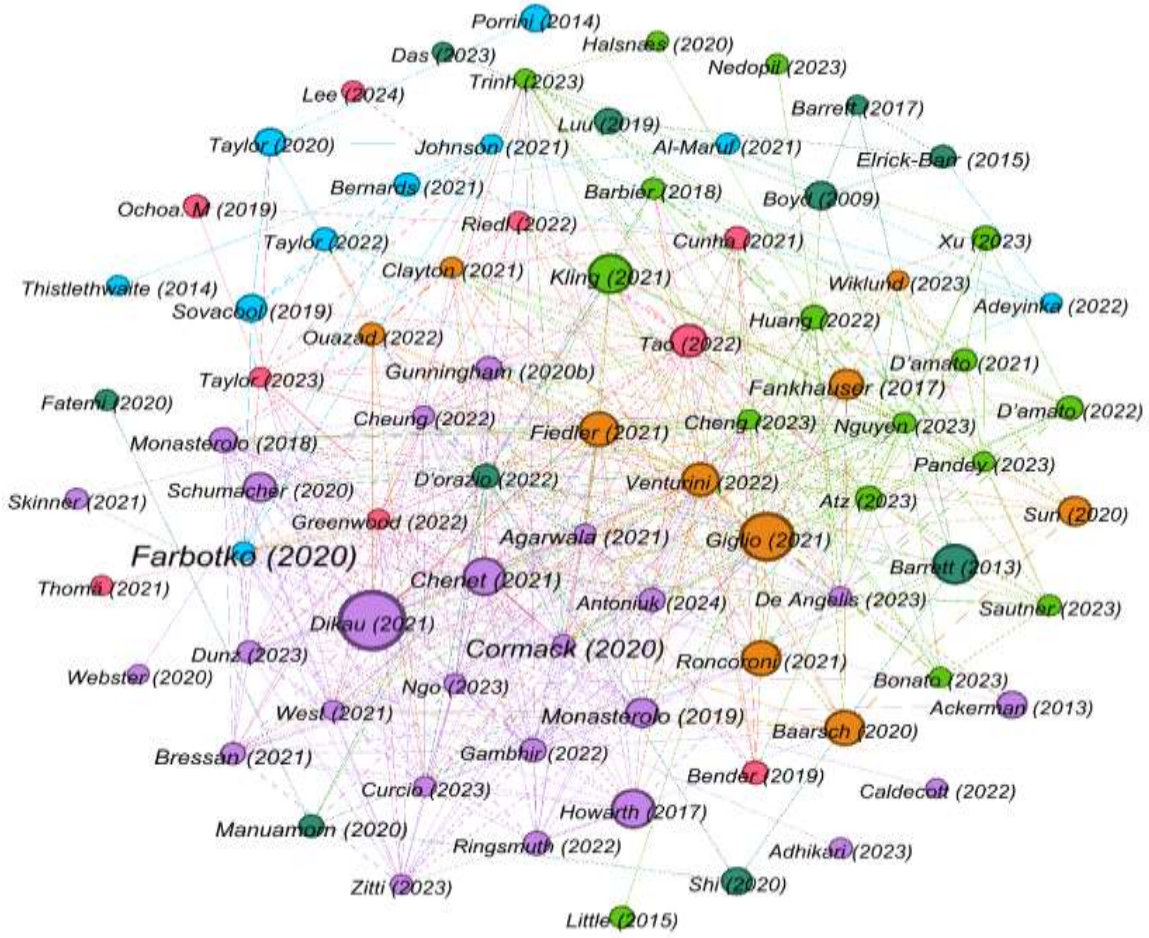

Figure 11. Bibliographic coupling of documents (Source: Gephi)

3.15.2. Corporate Sustainability, ESG, and Financial Performance:

There are 16 documents in Cluster 2 that look into the complicated connections between environmental issues, business sustainability, and money matters. Atz et al. (2023) do a thorough review of all the research that has been done on corporate sustainability, sustainable finance, and financial performance. Nedopil (2023), on the other hand, looks into why biodiversity risks are often ignored when making financial decisions and suggests ways to better include biodiversity concerns. D'Amato et al. (2022) and (2021) use machine learning to look into how structural data from companies, like items on the balance sheet, affects ESG scores. Huang et al. (2022) look into how firm-level climate risk affects loan terms and the chance of default, as well as how well climate risk management strategies work to lower these risks. Trinh et al. (2023) look into how green growth, new technologies, and trends in infrastructure

investment are connected in 56 different countries. Xu et al. (2023) look into how green credit policies affect China's companies' carbon emissions, and Bonato et al. (2023) check out how well climate risks can predict changes in the stock market. Nguyen et al. (2023) and Sautner et al. (2023) look into how climate risk affects a company's chance of going bankrupt and how risk premiums change when a company is exposed to climate change. Cheng et al. (2023) look into how green policies might help lower these costs and the financial effects that countries facing serious climate risks have on their sovereign bonds. The study by Pandey et al. (2024) looks at how the Glasgow Climate Pact impacts clean energy stocks, focussing on key factors that determine cumulative abnormal returns (CARs). Halsnaes et al. (2020) look into how the needs for climate services are changing in important areas so that green solutions can be found by 2050. Little et al. (2015) look into how climate derivatives, especially put options, can help finance adaptation to climate change in industries like Tasmanian salmon aquaculture. Barbier and Burgess (2017), on the other hand, look at how businesses can deal with climate risks. They come up with a model that shows how good risk management can lower a company's capital costs, which makes it more appealing to investors. Kling et al. (2021) investigate the effects of climate vulnerability on firms' financing costs and capital access, emphasising the impact of climate on financial performance. This cluster discusses various approaches to incorporating environmental risk and sustainability into financial decisions and corporate strategy.

3.15.3. Climate Risk, Insurance, and Socio-Economic Vulnerability:

In Cluster 3 ten documents included that examine different aspects of climate risk, finance, and the relationship between insurance, socioeconomic and environmental factors. Adeyinka et al. (2022) assess the scope and geographical distribution of climate index-based insurance (IBI) research, focussing its potential in developing countries to reduce climate risks and support agriculture-dependent economies. Taylor and Aalbers (2022) investigate how climate risk management practices in the real estate and finance sectors may worsen or create new pressures for climate gentrification. Al-Maruf et al. (2021) examine the WIBCI pilot project in Bangladesh, evaluating its challenges and suggesting enhancements for sustainable crop insurance. Thistlethwaite (2014) examines private environmental governance (PEG) as a mechanism for establishing political authority to promote sustainable finance practices. Johnson (2021) investigates the role of "ex gratia" payments in parametric insurance markets, in particular for addressing dissatisfaction resulting from the failure of market mechanisms. Furthermore, Sovacool et al. (2019) study the risks of inequality and injustice in climate change responses, specifically in the contexts of experimentation, financialisation, and dispossession. Farbotko (2020) underlines the systemic risks that global efforts to stabilise the climate-finance system pose to impoverished populations.

3.15.4. Market Dynamics, Asset Pricing, and Climate-Related Financial Risks:

Cluster 4 comprises ten essential documents that collectively examine the relationship between climate risks, economic stability, and financial markets. Wiklund (2023) evaluates physical climate risks linked to sustainable equity funds, contrasting them with general market benchmarks, and examines determinants affecting the climate risk exposure of these funds. Ouazad and Kahn (2022) examine the effects of natural disasters on mortgage securitisation, highlighting the tendency of some lenders to transfer disaster risk to government-sponsored enterprises (GSEs). They use data on hurricane damage to evaluate lender responses. Furthermore, Venturini (2022) analyses climate change as a market risk and also investigates the incorporation of climate-related risks into equity markets, and compares various analytical methods for assessing their impact on stock returns. Sun et al. (2020) investigate Chinese mining companies, assessing how climate change risks affect their financial performance. Baarsch et al. (2020) studied the impact of climate change on income convergence in Africa, examining scenarios in which it may help economic development. Fiedler et al. (2021) found

that the use and limitations of climate models in financial risk assessment, focusing the importance of reliable climate projections, the risks relation with climate data misuse, and the domains that require modelling enhancements. Roncoroni et al. (2021) studied the implications of climate policy shocks and market dynamics for financial stability. Fankhauser (2017) gives a thorough review regarding economic challenges related with climate change adaptation, summarising existing knowledge on adaptation economics and proposing areas for future research.

3.15.5. Climate Policy, Global Adaptation, and International Finance:

In Cluster 5, ten studies explored various facets of climate policy, adaptation, and finance across different geographical settings and frameworks. D'Orazio (2022) explores how G20 nations have embraced climate-related financial policies, employing cluster analysis to uncover trends from 2000 to 2018. Das and Ghosh (2023) explore decarbonization strategies in developing countries, focussing on India, and highlight how crucial institutional frameworks are for reaching "net-zero" emissions. Boyd and colleagues (2009) explore how climate adaptation and mitigation policies are integrated into development planning, looking at what has been achieved and what still needs to be done. Shi and Varuzzo (2020) explore how coastal cities in Massachusetts, situated in flood-prone areas, are evolving, looking closely at the financial impacts of these choices. Furthermore, Luu et al. (2019) explore the motivations of farmers in Vietnam's Red River Delta to change their agricultural practices in response to climate change. Fatemi et al. (2020) examines the incorporation of climate change factors into Bangladesh's national, sectoral, and local development strategies, showing differences in governance levels. Barrett (2017) emphasises the policy implications of transitioning from "adaptation finance" to "resilience finance," as well as the importance of including marginalised populations. Elrick-Barr et al. (2015) study how Australian coastal households perceive climate and non-climate risks, and how this affects their adaptive behaviours. Manuamorn et al. (2020) studied the factors that influence the prioritisation of vulnerable local communities in climate adaptation projects funded internationally.

3.15.6. Environmental Finance, Disclosure Practices, and Green Investment Strategies:

In Cluster 6 nine documents are included that examine different aspects of environmental finance, climate risk, and the financial sector's approach to sustainability challenges. Tao et al. (2022) conducted a bibliometric analysis to delineate research streams in environmental finance, mapping existing themes and suggesting avenues for future inquiry. Greenwood and Warren (2022) investigate the approaches of UK asset managers related to climate risk disclosure and management strategies, with a particular focus on the impact of organisational factors on low-carbon investment. Lee et al. (2024) investigate the impact of green finance on China's energy transition, focussing on the issue of climate risk in achieving this transition. Furthermore, Taylor (2023) addressed the perspectives and responses of finance professionals, particularly analysts, to the economic and social consequences of climate change. Cunha et al. (2021) investigate climate-related investments in Brazil's equity market and compare the performance of low-carbon investments to traditional benchmarks to analyze the difference in performance across different economic and political environments. Ochoa et al. (2019) investigate how household characteristics influence crop diversification in Ecuador's Laipuna Reserve, using the Shannon index to measure farm-level diversification. Riedl (2022) examines market participants and incentives that influence corporate and financial climate risk management practices. Thomä et al. (2021) discuss how informing investors about portfolio alignment with the Paris Agreement influences their future behaviour. Furthermore, Bender et al. (2019) conduct an empirical analysis of climate risk from an investment standpoint, survey existing metrics on climate-related investments, and propose a framework for better-integrating climate mitigation and adaptation into public equity strategies. These analyses improve our

understanding of how the financial sector responds to climate and environmental concerns, emphasizing the importance of frameworks, metrics, and strategies that support sustainable finance.

4. Conclusion and discussion

Growing attention is being given to the relationship between climate risk and biodiversity, emphasising the necessity of incorporating environmental sustainability into financial risk management. The significance of environmental, social, and governance (ESG) considerations in investments, the function of international conventions, and the difficulties in modifying financial models to take biodiversity loss and climate change into account are some of the major themes. To address these interrelated risks and advance sustainable economic practices, the analysis highlights the need for creative, multidisciplinary approaches. Through an in-depth bibliometric analysis, we have identified significant trends, influential articles, authors, and institutions, illuminating the research trajectory in this field. Subsequently, policymakers, practitioners, and researchers must keep going in investigating and addressing the interrelation of biodiversity and climate risk, utilising insights from this analysis to facilitate informed decision-making and promote sustainable development pathways.

Table 6. Summary of findings

Analysis	**Result**
Total publication	162
Citation	2847
Total cited publications	136
Collaborated articles	125
Most influential article	*Title:* Central bank mandates, sustainability objectives and the promotion of green finance *Citations:* 199
Most productive journal	Journal of sustainable finance and investment (11 publications)
Most influential journal	Ecological Economics (396 citations)
Most productive country	United Kingdom (31 publications)
Most influential country	United Kingdom (199 citations)
Most productive organization	Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon (4 documents)
Most influential organization	Vienna University of Economics and Business, Austria (85 citations)
Most productive author	Irene Monasterolo and Ulrich Volz (6 publications)
Most influential author	Dikau S. and Volz U. (199 citations)
Themes	Climate Resilience and Strategic Financial Adaptation, Corporate Sustainability, ESG, and Financial Performance, Climate Risk, Insurance, and Socio-Economic Vulnerability, Market Dynamics, Asset Pricing, and Climate-Related Financial Risks, Climate Policy, Global Adaptation, and International Finance, Environmental Finance, Disclosure Practices, and Green Investment Strategies
Bibliographic coupling of authors	Purple Cluster: Volz, Ulrich Orange Cluster: Monasterolo, Irene Green Cluster: D'ecclesa, Rita
Bibliographic coupling of journals	Purple Cluster: Sustainability (Switzerland) - 53 Orange Cluster: Ecological Economics - 163 Green Cluster: Journal of Sustainable Finance and Investment – 121
Bibliographic coupling of countries	Purple Cluster: China – 1820 Orange Cluster: United Kingdom – 8163 Green Cluster: Germany – 5362
Bibliographic coupling of documents	Purple Cluster: Dikau (2021) Orange Cluster: Giglio (2021) Light Green Cluster: Kling (2021) Dark Green Cluster: Barrett (2013) Blue Cluster: Sovacool (2019) Pink Cluster: Tao (2022)

Notes: This table summarizes the findings of this study.

We have defined the main conclusions of this review: The descriptive analysis of the dataset reveals a steady growth in research output within the field from 2006 to 2024, with a total of 162 documents analysed. Scholarly productivity has significantly increased, peaking in 2023 with 54 publications. While 2021 recorded the highest total citations (854.91) and an average of 40.71 citations per publication, a notable decline in average citations per publication was observed in subsequent years, falling to 2.35 in 2024. This trend indicates the changing significance of recent publications, which is most likely due to new research domains or a short citation accumulation timeframe. The dataset shows a dynamic trend of increasing academic contributions, which is accompanied by changes in citation impact and scholarly influence over the study period.

Second, Irene Monasterolo and Ulrich Volz emerge as the most productive authors in the areas of biodiversity and climate risk, each with six publications. Volz has 360 total citations, 60 per document, indicating a significant impact. Particularly, Hugues Chenet ranks first among the most cited authors, with two publications receiving an impressive 73 citations each. Similarly, Stefano Battiston has a significant impact, with an average of 56 citations across two documents. Despite the moderate citation impacts of contributors like Campiglio, Knaepen, and Magnuszewski, this analysis reveals a substantial diversity in productivity and influence among authors in the fields of biodiversity and climate risk.

Third, the most cited document analysis shows that Dikau's (2021) "Central bank mandates, sustainability objectives, and the promotion of green finance" article has 199 total citations, demonstrating its significant impact in the area of study. In terms of average citations, "Climate Finance" by Giglio (2021), with 144, and "Adaptation finance and vulnerability reduction" by Barrett (2013), with 102, are among the most significant publications. Furthermore, "The impact of climate vulnerability on firms' cost of capital and access to finance" by Kling (2021) and "Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy" by Chenet (2021), articles highlight key contributions to the connection of climate and financial research.

Fourth, the Journal of Sustainable Finance and Investment is the most productive and frequently cited source, with 11 publications and an average of 15.55 citations. Ecological Economics has the highest average citation rate, with 79.20 citations per document, indicating its significant influence in the area of study. The two journals, World Development and Global Environmental Change have a high citation impact because they register 60.67 and 55 cites per document, respectively. Besides that, Nature Climate Change and Environmental Science and Policy have achieved a citation rate of more than 50 per document, so they play a very important role in discussing biodiversity, risk, and sustainability.

Fifth, an analysis of the most productive institutions reveals that the Vienna University of Economics and Business has the highest citation per document rate at 28.33, derived from three publications. On the other hand, the German Development Institute in Bonn has a citation per document rate of 20 based on three articles, showing how important its research contributions are. Other top organizations are Excelia Business School in France and the Potsdam Institute for Climate Change Research in Germany respectively with citations per document, 18 and 17, indicating, although there are fewer research articles, there are highly influential research outputs. This data shows a diverse range of high-impact research from specialised institutions in Europe and North America, showing global collaboration in the advancement of sustainability and climate change research.

Sixth, the keyword co-occurrence analysis shows that "Sustainable Finance", "Climate Change", and "Climate Risk" are central nodes that connect important areas such as "Green Finance", "Systemic Risk", and "Transition Risk". Emerging themes such as "Biodiversity Risk," "Machine Learning," and "Green Bonds" indicate increased research interest in novel and specialised topics. The addition of policy terms like TCFD and the Paris Agreement

underlines the inclusion of global governance frameworks into financial, biodiversity, and climate risk discussions. The network underlines the interdisciplinary nature of sustainable finance research by connecting financial systems to environmental risks and global sustainability objectives.

Seventh, the analysis of the co-authorship network reveals that authors such as Christopher P.O. Reyer, Ulrich Volz, and Irene Monasterolo are pivotal nodes, suggesting elevated degrees of collaboration and influence within the discipline. Notable contributors, including Hugues Chenet and Emanuele Campiglio, assume crucial roles in the integration of diverse research clusters, thereby highlighting their significance in fostering multidisciplinary and international cooperation. This network underlines how the authors are proactively taking part in promoting collaboration across different subfields of research to emphasize joint efforts in sustainability, biodiversity, and climate risk research.

This study, therefore provides valuable insights into the interaction between collaboration within sustainable finance, biodiversity risk, and climate risk, yet some limitations have to be noted. Firstly, the scope of our study was confined to the Scopus database, while future studies can complement their validity by incorporating databases such as Web of Science and Inder Sciences. Moreover, the search string used in this study contains not all relevant articles, thereby limiting the scope of the study. This study only limits its scope to authors and institutions operating in the areas of finance and economics. Other future studies can expand their scope to include other interdisciplinary areas such as policy studies or environmental science to reach a comprehensive and clear understanding of the research landscape of the world.

5. Future research agenda

The emerging relationship between biodiversity and climate risk has underscored numerous critical research domains that necessitate further investigation. Despite substantial advancements by researchers in comprehending the effects of biodiversity and climate risks on economic stability, considerable gaps remain in the incorporation of these ecological risks into financial models and investment strategies. In addition, the complexity of ecosystems and natural environments related to their unpredictable behavior and sensitivity toward disturbances is typically ignored in recent developments in risk assessment procedures. On the other hand, it is essential to interrogate international agreements such as the CBD and UNFCCC to identify how these systems could impact financial markets, policy-making, and strategic firm behavior. Therefore, we have the following Future Research Questions for the exploration:

FRQ1. How can financial institutions integrate biodiversity and climate risks into their risk management strategies, accounting for the nonlinear and dynamic nature of ecological systems?

FRQ2. How can investment models incorporate ecosystem services and biodiversity risks more effectively to drive private investment towards sustainable and resilient economic practices?

FRQ3. How can interdisciplinary approaches combining ecology, economics, and finance be leveraged to create new models that predict and manage the complex interactions between biodiversity and climate risks?

FRQ4. What are the mechanisms through which environmental, social, and governance (ESG) factors related to biodiversity and climate risk influence corporate financial performance and market stability?

FRQ5. How do international conventions such as the CBD and the UNFCCC influence the development of financial instruments and investment strategies focused on mitigating biodiversity and climate risks?

FRQ6. What are the key barriers to incorporating biodiversity and climate risks into the decision-making processes of financial markets, and how can these barriers be overcome?

Addressing these FRQs will help bridge the current gaps in literature and practice, offering novel insights into how the financial sector can more effectively integrate biodiversity and climate risks into their frameworks and strategies. This research agenda will be instrumental in promoting sustainable and resilient economic development in the face of escalating environmental challenges.

Declaration of Conflict of Interest

The authors affirm that no conflicting financial or personal interests could have impacted the findings of this paper.

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